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

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CAP LTER PHASE 2
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I. OVERVIEW OF RESULTS AND BROADER IMPACTS

Overview

CAP2, the second phase of the Central Arizona-Phoenix LTER (NSF #DEB-0423704), builds upon a 7-year foundation of a comprehensive investigation of rapidly growing metropolitan Phoenix, Arizona. This year marks the first formal year of the CAP LTER renewal, although some research conducted during 2004-2005 was supported through CAP1 supplemental funds under a no-cost extension. A separate report for CAP1 (NSF #DEB-9714833) has been submitted for the work conducted describing activities and findings for the North Desert Village Suburb experiment and the Phoenix Area Social Survey; however, it has been repeated in this report in order to provide a full picture of this year's accomplishments.

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

For this report, we highlight projects within each of the integrative project areas, which were chosen to encompass the traditional LTER core areas while embracing an interdisciplinary approach (Fig. 1). We also report progress on over-arching monitoring and experimental programs that cross all of the project areas, and on development of data resources and information technology. We have made progress in ecosystem modeling applied to the desert region and in models of urban growth specific to Phoenix. In CAP1, we established an extensive long-term integrated field inventory (Survey 200), to be repeated every five years (Hope *et al.* 2003), and we completed the second survey in spring 2005. We completed installation of a first-of-its-kind experimental manipulation of residential landscapes with people actually living on them (Cook *et al.* 2004), concluded a pilot landscape experiment, and initiated long-term fertilization experiments with leveraged funding.

CAP LTER participants published 234 journal articles, books, and book chapters since its inception in 1997 through 2004. This year (2004-2005) 74 publications have been published or are currently in press/review. Ninety-seven individual scientists are actively working on the CAP LTER or affiliated projects, including 47 faculty members, 10 post-doctoral scholars, 9 graduate students, 11 undergraduate students, and 17 technicians. CAP scientists made over 31 presentations at national and international meetings during the first year of CAP2. Finally, CAP has leveraged funding for several large projects that complement its basic science emphasis. Active or newly funded during 2004-2005 were a study of resilience of urban water institutions (McDonnell Foundation, Kinzig and Redman 2002), "Agrarian Landscapes in Transition," a multi-LTER project (NSF-BCE, Redman *et al.* 2002), a study of N retention in urban streams (part of LINX-2, NSF-IRCEB, Mulholland *et al.* 2001), "Decision Center for a Desert City," a program aimed at (NSF-SBE's Decision-Making Under Uncertainty program; Gober *et al.* 2003), a study of the effects of elevated N and organic C deposition in and around the urban ecosystem (NSF-Ecosystems, Grimm *et al.* 2005), and a study of the effects of urbanization on trophic dynamics (NSF-Ecology, Faeth and Sabo 2005).

Broader Impacts

CAP LTER's broader impacts are in three main areas: raising national awareness and profile of urban ecology, education and outreach, and decision making in Greater Phoenix. Individual scientists from CAP have been tapped extensively to contribute to international discussions of urbanization and sustainability; for example, Redman is a member of the international U.S. National Committee on the Scientific Committee on Problems of the Environment (SCOPE). Briggs has been an active participant in NEON and LTER planning activities, and Grimm has been invited to co-chair a sustainability conference in China. CAP LTER's program at the K-12 level, Ecology Explorers, has over 100 teacher-participants at 94 public schools (encompassing 31 school districts), 4 charter schools, and 2 private schools. Several faculty members and graduate students participate in ASU's Community of Undergraduate Research Scholars program by mentoring undergraduate students in urban research. We have 13 active fellows, 6 associates, and 5 graduated fellows (emeriti) in our Integrative Graduate Education and Research Training (IGERT) program in urban ecology, which has been renewed this year. Finally, over 20 community partners are engaged in CAP LTER, such as Salt River Project, Maricopa Association of Governments, the U.S. Geological Survey (USGS), and the Gila River and Salt River-Pima Indian communities. Details on our education and outreach efforts appear in sections VI and VII of this report.

The role of CAP in decision making in Greater Phoenix has been enhanced by funded projects that promote community and governmental outreach. While preserving our scientific objectivity, we have benefited from the establishment of projects that are more directly linked to local and regional government. For example, the Greater Phoenix 2100 (GP 2100) project and the Decision Center for a Desert City draw on CAP LTER data to help policy makers and others envision the long-term future of the greater Phoenix region (Fink *et al.* 2003, Gober in press). In addition, our information-management team continues to play a leadership role in developing new IT tools for handling ecological data.

II. Research Activities

Research Design and Approach

Although our program is fundamentally ecological (*sensu* Likens 1992), we include humans among the organisms interacting and participating in fluxes of energy and materials, and contend that an ecological study must monitor and interpret change from a perspective that includes humans as part of nature (Cronon 1995, Kinzig *et al*. 2000, Kaye *et al.* in review). Research thus must integrate social science research, requires longer time horizons, and must be informed by flexible models and multiscaled data. To fully operationalize this integration, we organize our research under five integrative project areas (IPAs): land-use and land-cover change; climate-ecosystem interactions; water policy, use, and supply; fluxes of materials and socio-ecosystem response; and human control of biodiversity. Several projects are affiliated with multiple IPAs and are described below under the heading "Ongoing Research": Survey 200, the North Desert Village (NDV) experiment, and the neighborhood-scale Phoenix Area Social Survey (PASS).

Land-Use and Land-Cover Change (LULCC)

Land use and land cover define the context of the socioecosystem, and alterations in their patterns underlie most other ecosystem changes. We ask: How have land use and land cover changed in the past, and how are they changing today? 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? The land-use and land-cover change (LULCC) IPA's developing understanding of the answers to these questions sets the stage for all other IPA research. In this report, we highlight the Phoenix Area Social Survey findings (see activities under PASS) and a new, high-resolution, land-cover classification and urban-growth modeling activities, although accrual to our database of remotely sensed land-cover data and historic land-use data continues.

Climate-Ecosystem Interactions (CLIM-ECOS)

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 interactions (hereafter, CLIM-ECOS) are conducted at multiple scales from single organism to region. 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? In CAP2, we have completed initial ecosystem modeling that allows us to accurately predict desert net primary productivity. Further modeling experiments (e.g., manipulating heat or material inputs or changing plant composition) can now be conducted with confidence. We also report initial findings for climate-ecosystem team portions of two projects conducted at the neighborhood scale, one experimental (NDV) and one observational (PASS), which are described under "Ongoing Research."

Water Policy, Use, and Supply (WATER)

Humans now appropriate 100% of the surface flow of the Salt River (Phoenix's river) and are increasingly exploiting groundwater resources and surface waters from more distant basins (e.g., 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 WATER IPA, we examine landscape water management, water supply and delivery, riparian restoration, and resilience of the socioecosystem to water-related stress or catastrophe. This is a new area of emphasis for CAP2, and during year 1 we initiated one or two pilot projects and completed a conceptual analysis of the effects of urbanization on stream biogeochemistry. Our work in this area is well integrated with the Decision Center for a Desert City with its focus on water management.

Material Fluxes and SocioEcosystem Response (FLUXES)

Material fluxes and biogeochemical linkages have been studied for decades in relatively undisturbed ecosystems, but not in urban ecosystems where human-generated fluxes of nutrients and toxins are coupled with nonhuman biogeochemistry. The main question driving this IPA (termed FLUXES) 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? In this report, we highlight new research initiated on metal distributions in soils and several completed analyses from soils work in the Survey 200. We also report on the setup of a new atmospheric deposition study and long-term fertilization experiment.

Human Control of Biodiversity (BIODIV)

Ecological approaches to studying human control of biodiversity (hereafter, BIODIV) have typically focused upon habitat loss and disturbance brought about by humans at high population densities. We 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? The first year of CAP2 has seen the publication of several syntheses of long-term bird and arthropod monitoring data, along with completion of a neighborhood park project designed to explore the relationships between socioeconomic and ecological variables. The park project was redesigned to complement the new PASS project, which is described in "Ongoing Research" below. The human control of biodiversity team actively participated in Survey 200 and the NDV experiment, both also described under "Ongoing Research."

Ongoing Research

Ongoing research activities not described above are affiliated with more than one IPA. These include the Survey 200, extensive sampling conducted once every five years; the North Desert Village Experiment; and the neighborhood-scale Phoenix Area Social Survey. Findings are reported under the individual IPAs but will refer to these shortened titles. We also have several working groups, not all of which fall cleanly within the IPA structure. Working groups active during 2004-2005 include: models and conceptual development; long-term experiments; soils; remote sensing; and education, informatics, and knowledge exchange. Here we summarize activities of those working groups, with findings reported under appropriate IPAs.

Survey 200. As an overarching monitoring project, we collect data in the Survey 200 that is relevant to all of the IPAs. The 200-point extensive sampling program (Survey 200) is an extensive field survey designed to provide a snapshot of broad-scale spatial variations in key ecological variables across the CAP region. Designed to be repeated once every 5 years, it also provides one of the central parts of CAP's monitoring of ecosystem change over time. First carried out in spring 2000, the survey was successfully repeated this spring, with access again being gained to all but 2 of the 206 sites. The core suite of variables measured in 2000 (plants identified to genus, plant size measurements, soil coring, insect sweep net sampling, mycorrhizal soil sampling), were repeated, but this time around, all plants (including annuals) were identified to species and a herbarium voucher specimen collected of every species on every site. Given the wet conditions over winter and early spring in the region, annual growth was abundant and cataloging spatial variations in annual diversity across the region will yield valuable data. Processing and analysis of the soil core samples will be ongoing over the next 12 months. Comparison of soil chemistry between 2000 and 2005 will be carried out to examine how spatial patterning and overall soil nutrient pools have been affected by rapid regional urbanization. Additionally, total elemental analysis will be carried out on soil subsamples from every site, using ICP-MS, with a focus on heavy and trace metals. In 2004-2005, we continued analysis of the data from 2000, employing several innovative spatial analysis techniques including hierarchical bayes, spatial autocorrelation analysis, and kriging.

The North Desert Village (NDV) Experiment. The NDV community landscape experiment at ASU Polytechnic is designed to give a platform for CAP LTER researchers to study human-landscape interactions. Experimental tests of such reciprocal interactions are virtually unknown in urban ecology (Cook *et al* 2004). Major research questions include: a) How do landscape design and irrigation methods affect NPP and undercanopy microclimate, soil nutrient pools and fluxes, insect abundance and diversity, bird activity? and 2) How does landscape design affect direct human-landscape interactions in terms of both perceptions and behaviors?

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). These are: mesic/flood irrigation—a mixture of exotic high water-use vegetation and shade trees with turf grass; oasis—a mixture of drip-watered, high and low water-use plants on granite substrate, and sprinkler-irrigated turf grass; xeric—individually watered, low water-use exotic and native plants on granite substrate; and native—native Sonoran Desert plants on granite substrate and no supplemental water. Six additional households will be monitored as no-plant, no-water controls. Landscaping work commenced in Fall 2004 and was completed in Summer 2005, involving preparing the ground, trenching and installation of irrigation systems, planting trees and shrubs, cactis and succulents, establishing turf, and spreading decomposing granite.

Pre-treatment baseline surveys began in fall 2003 and are completed; these included: a) FLUXES team—soil-profile characterizations (by the Natural Resources Conservation Service), soil physical and chemical properties, and trace-gas flux monitoring; b) BIODIV team—mycorrhizal species identification, ground arthropod and bird abundance and diversity surveys, and human-occupant surveys; and c) CLIM-ECOS team—estimations of above- and below-ground vegetation biomass. The CLIM-ECOS team is currently installing micrometeorological stations within each of the six mini-neighborhoods (blocked planting/water-regime treatments), in addition to a standard meteorological installation for the entire NDV area. We will monitor several parameters, which will allow us to answer our main questions as well as discern the effects of residential landscape design on a suite of neighborhood physical, chemical, biotic, and social variables. In this report, we present findings from the soil and human-occupant surveys.

Phoenix Area Social Survey (PASS): The main objective of PASS is to examine the reciprocal relationships, or interplay, between social and natural environments in an urban ecosystem using a survey at the neighborhood scale. The neighborhood can be used to integrate data from several disciplines in order to study the social organization of human activity, ecological services, and microclimates. Neighborhoods are unique but interconnected, socioecological systems that bridge elemental social and ecological patterns and processes with larger-scale social and biophysical phenomena. A pilot survey was conducted in 2001 in eight neighborhoods located at Survey 200 sites in the city of Phoenix. Neighborhoods were selected to represent different types of urban communities in terms of median income, ethnicity, age of housing stock, types of landscaping, and locations, and 302 respondents were interviewed by telephone and in person. Results from the pilot study (Larsen *et al.* 2004, Harlan *et al.* 2003) demonstrated the importance of developing a long-term social monitoring study that will integrate with most of the IPAs. The long-term PASS will:

- Examine how communities form and how they work in a rapidly growing, low-density urban setting characterized by high rates of in- and out-migration and frequent residential mobility within the metropolis.
- Study the interaction between rapidly growing human communities and the natural environment in a desert ecosystem.
- Explore the possibilities of interdisciplinary research that combines a spatially referenced social survey (i.e., households in selected neighborhoods) with other sources of population, ecological, and climate data.

- Establish the methodology for an on-going area survey that will continually explore issues of sociological, ecological and social policy interest in the Phoenix metropolitan area.

In 2004-2005, we secured funding for a new and expanded version of PASS II from a CAP LTER Supplement Grant. The original eight PASS neighborhoods will be re-surveyed and eight new neighborhoods will be added to the sample. The new survey will provide social monitoring at a larger number of Survey 200 sites and allow us to capture more of the social diversity that exists in the metropolitan area. Planning for PASS II was initiated, with steps taken toward selecting new sites and discussions of topical focus. We used an analysis by P. Gober (unpublished) of all census tracts in the metro area in order to categorize each Survey 200 neighborhood as one of several demographic types. This will enable us to strategically select different types of neighborhoods for our sample. We held two planning meetings with interested faculty who discussed priorities for the topics that will be covered in PASS II. A focus on population growth and community, air and climate, neighborhood 'configuration'/landscape, and water were identified as important areas for investigation and planning groups were formed in each focus area. We also made plans with researchers at the University of Michigan to coordinate some of the content of PASS with a survey of environmental attitudes in the Detroit metropolitan area.

Analysis of data from PASS I continued, resulting in several publications. Records of household water consumption data obtained from the Phoenix Water Resources Department were linked to all households in the eight PASS neighborhoods. Preliminary analyses of water consumption and demographic characteristics of households were conducted. Finally, we created a project web site (http://caplter.asu.edu/passne).

<u>Working groups</u> active during 2004-2005 met periodically to tackle various challenges. The <u>models and conceptual development working group</u> hosted a workshop with invited guests John Bolte and David Hulse of Oregon's Willamette Futures project, at which several CAP participants and participants new to the project presented their conceptual models for the CAP ecosystem. The group is working through these models to further develop the overall conceptual framework of the project. The <u>long-term experiments</u> working group made decisions to invest primarily in the NDV and long-term fertilization experiments (see FLUXES), but to curtail activities at the DBG pilot landscape experiment (Stabler and Martin 2000, 2004) at the end of 2005. The <u>soils</u> working group has mainly concentrated on working up results from the 2000 Survey 200 (described above), whereas the <u>remote sensing</u> working group recommended several new products for acquisition by the project, ensuring availability of imagery for the years of the Survey 200 and other key time periods. Knowledge exchange with urban policy makers, managers, and stakeholders is as fundamental to our project as the core scientific activities. Although the <u>education, informatics, and knowledge exchange</u> working group did not actively meet, we have been successful in leveraging LTER funding to accomplish outreach and data-management objectives that are beyond the capability of the CAP LTER, and many of our scientists are active in those projects.

III. Highlights of Research Findings

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

Land-Use and Land-Cover Change (LULCC)

Ecosystem modeling in CAP LTER has the objective of predicting basic ecosystem process rates for different patch types within the urbanized central Arizona region, at a range of scales (Wu *et al.* in press, Wu and David 2002). While the hierarchical patch dynamics paradigm is our guiding framework, a suite of modeling approaches is used, including cellular automata, spatial Markov processes, multi-agent systems, and process-based modeling. The modeling work is assisted with remote sensing data and geographic information systems (GIS). The modeling project also is developing scaling strategies to extrapolate plot-level information to the landscape and regional scales (e.g., Jenerette *et al.* in press b; see FLUXES).

Urban growth modeling is being conducted with the UrbanSim model. In conjunction with other projects, such as the NSF-Biocomplexity MUSES incubation project on material use, researchers are acquiring data to set model parameters. Preliminary results have shown the utility of this model for developing scenarios of land use and demographic changes that may result from the proposed light rail system in Phoenix (Joshi et al. 2005) and impacts of urban growth on material use in housing construction as well as the air quality impacts of such materials (Li et al. 2005).

Use of remote sensing to quantify and classify land cover and changes in pattern has continued in CAP2. Datasets are available for key years and are frequently used in concert with other variables; in addition, these classification data are useful for comparisons and modeling. To evaluate uncertainty in vegetation estimation from remote sensing, for example, several regression techniques were used to compare methods (Buyantuyev *et al.* in review). Vegetation abundance was estimated from three Landsat images using two different methods—vegetation indices (NDVI and SAVI) and linear Spectral Mixture Analysis (SMA). Images that exhibited the highest correlation with field data were used in regression analysis. Alternative regression models, including Ordinary Least Squares (OLS), inverse OLS, OLSbisector, and Reduced Major Axis (RMA) were constructed separately for urban, desert, and agricultural land uses. SMA, which models subpixel fractions of the vegetation endmember, was found to improve the accuracy of empirical relationships for urban (four-endmember model) and especially for desert (five-endmember model) sites where the difference from any one vegetation index was 20% of explained variation in cover. Comprehensive uncertainty analysis of these theoretically different regression models was based on root mean square errors (RMSE), systematic errors (SE), bias, and variance ratios. We found that overall RMA regression provided a better fit for desert plots (lower slope variability, lower RMSE than OLSbisector, closest to unity variance ratio, and no bias). Despite its large bias and lower variance ratio, OLS was considered a better model for urban plots given a consistently lower variation in slope and lower RMSE. However the use of OLS, which assumes no measurement errors in predictor variables, should be considered theoretically flawed.

A High-Resolution Urban Forest Classification System for Phoenix was developed for delineation of woody vegetation in an arid urban ecosystem using high resolution, true-color aerial photography (Walker and Briggs in review). We adopted an object-oriented approach due to the physical nature of high-resolution photography, in which the objects of interest were composed of few to many pixels. Similarity of adjacent pixels in a region was used to group them into polygonal objects. These objects were spectrally analyzed for discrimination between woody vegetation and all other objects. The classification was parameterized to highlight woody vegetation for further environmental and ecological modeling. Accuracy assessment within subclasses showed highest producer's accuracy for tree species with large, dense foliage. Error was shown to be related to plant size, leaf color and canopy density. This procedure produces a binary matrix where the entire raster set is classified, highlighting the elements of the urban forest.

The Phoenix Area Social Survey (PASS) examines the interplay between the social and natural environments in an urban ecosystem. Our central research questions for PASS I ask how neighborhood social ties, values, and behaviors are connected with one another in ways that reflect willingness to act socially and politically with respect to the environment, and how changing environmental conditions, in turn, affect the quality of human life. Highlights of results from PASS I analyses (e.g., Larsen and Harlan in press, Kirby *et al.* in press) in 2004-2005 are:

- Bonding social capital (strong social ties and interpersonal trust among neighbors) was higher for people with more educational attainment, longer-term residents, and non-Hispanics. Neighborhood-level residential stability and concentrated affluence also contributed to an individual resident's level of bonding social capital. Neighborhood-concentrated poverty, however, reduced bonding among neighbors. Individuals with higher levels of bonding social capital and higher educational attainment were more likely to take civic action on neighborhood problems. These included environmental problems such as noise, construction and other development-related issues, hazardous materials, and toxic emissions.
- Comparing the attitudes of homeowners in Home-Owners' Associations (HOA) and traditional neighborhoods about communal values and security, we found that anecdotal assertions about the extreme behaviors HOA residents and the negative implications of HOA governance structures for consensual community may be exaggerated concerns. HOA residents were very familiar with the legal codes of the associations but few had been active participants in governance. A large majority had favorable attitudes toward HOAs as protectors of property values and for keeping the neighborhood running smoothly. HOA residents were about evenly divided between those who believed the HOA encourages sociability between neighbors and those who believed it impedes relations. HOA residents were similar to non-HOA residents in having a feeling of community in their neighborhood.
- Despite being frequent movers, most people in Phoenix have feelings of attachment to their neighborhoods; they form emotional attachments with place and social bonds with neighbors. Attachment increased with length of residence but perceptions of the neighborhood environment were more important than longevity in predicting attachment. The most important factor affecting attachment was the perception that neighbors exercised collective control over what happens in the neighborhood. People's perceptions of the neighborhood environment transcended the conventional boundaries that scientists construct between social and physical attributes of a place. Perceptions of neighborhood biophysical elements, such as perceptions of bird diversity, access to nature, and level of pollution, contributed to place attachment.

Climate-Ecosystem Interactions (CLIM-ECO)

Understanding the controls on aboveground net primary productivity (ANPP) is a fundamental goal for any LTER project. At CAP, we made substantial progress in modeling ANPP during 2004-2005 as part of the project, Effects of Urbanization on the Landscape Pattern and Ecosystem Processes in the Phoenix Metropolitan Region: A Multiple-Scale Study. Investigators have taken the approach of adapting an existing ecosystem model, Patch Arid Land

Simulator-Functional Types (PALS-FT), to Sonoran Desert vegetation (Shen *et al.* in press). Future modifications will be used to adapt PALS-FT to urban patches, and simulations will be performed to explore how temperature, irrigation, and N deposition may influence desert ANPP.

Results this year showed that PALS-FT was able to simulate ANPP of a typical, creosote-bursage- (*Larrea-Ambrosia)* dominated Sonoran Desert ecosystem reasonably well, with a relative error of ~2.4% at the ecosystem level and generally ~25% at the functional-type level (Shen *et al.* in press). We used the model to simulate 15 y of ANPP and its seasonal and inter-annual dynamics for desert patches within the CAP LTER study area, yielding estimated average annual ANPP of 72.3 g m^{-2} y^{-1} and a range from 11.3 g m^{-2} y^{-1} to 229.6 g m^{-2} y^{-1} that corresponded to variation in rainfall. These values are close to field observations in other areas of the Sonoran Desert, and the range of variation also is similar to reports for arid and semiarid ecosystems. The dynamics of ecosystem ANPP in response to fluctuations in annual precipitation simulated by the model agreed well with the known relationship between ANPP and precipitation in arid and semiarid systems, but closer examination revealed the importance of seasonal distribution of rainfall. A comparison between the PALS-FT model prediction and two regression models for North American warm deserts showed that both regression models underestimated the ecosystem ANPP, while the process-based PALS-FT model provided the most accurate estimation among the three models (Shen *et al.* in press).

Findings from PASS also are germane to controls on ANPP in an urban ecosystem. The residential landscape constitutes a significant portion of the urban environment. In both front and backyards, a majority of people in Phoenix preferred the greener choices of lawn and oasis yards compared to desert landscaping (Larsen and Harlan in press), a finding consistent with preliminary fundings from the NDV experiment (see BIODIV). However, preference for desert landscaping (perceived by many as the socially correct choice) was more prevalent in the front than in the backyard. Desert frontyard landscaping was more prevalent among middle class homeowners, whereas upper-income homeowners preferred the oasis type by a slight margin, and lower-income homeowners preferred lawn. The evidence suggests that frontyard choices were motivated more by concern about appearance than by environmental concerns about water usage. In the backyard, appearance and a desire for play and recreational space were much more important than environmental concerns. Developers are exerting increasing control over frontyards and this is evident in newer homes, where desert landscaping is becoming more prevalent. In the backyards, however, people continued to have greener styles and there was more residential greenery in higher-income neighborhoods than in lower-income areas.

The Neighborhood Ecosystem Project is supported in part through a leveraged, NSF-Biocomplexity grant to continue and expand investigation started with PASS, and will continue to be linked with that project. Neighborhood Ecosystems is an interdisciplinary study of the impact of urbanization on human-ecological-climate interactions in the Phoenix metropolitan area where agricultural and desert land is rapidly being converted into residential neighborhoods. Investigators from five disciplines—sociology, geography, ecology, geological sciences, and planning—worked closely together to examine the vulnerability of human populations in different neighborhoods to the urban heat island, a major climate stressor. 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.

Data were collected regionally in census tract units (~1 mi^2 or 2.6 km^2) over an area of approximately 2,400 km^2, as well as for eight neighborhoods defined by census block groups, which are smaller and more homogeneous areas than tracts. Regionally, we combined remotely sensed satellite imagery (vegetation abundance and surface temperature), U.S. Census (population characteristics), and a digital-elevation model of the region's topography. For the eight PASS neighborhoods, in addition to scaling the regional data down to block group boundaries, we also monitored microclimates using portable air temperature/dew point loggers for 12 consecutive months (set to record at 5-min intervals). These data were analyzed by faculty and students using GIS mapping software, statistical procedures, in-depth qualitative analysis of the sites, and a computer simulation model of human thermal comfort. Findings this year indicate:

- Human settlement alters the urban climate and spatial differences in temperature can be detected at the local or neighborhood scale. Population density, thought by many climatologists to be the most visible indicator of human activity that affects climate, was not as important as the socioeconomic status of residents for predicting the spatial distribution of summer temperatures across the Phoenix region. Whether surface temperature was measured over the entire region or air temperature was measured in a sample of neighborhoods selected to represent different socioeconomic and ethnic groups, the summer urban heat island was more intense in low-income, predominately minority (Latino) areas. Overall, every \$10,000 increase in annual median household income for the neighborhood (defined by census tract) was associated with a 0.28^{o}C decrease in surface temperature on a summer day in the Phoenix metropolitan region. During a summer heat wave, air temperature at 1700 h varied by as much as 7.5^{o}C between an upper-income and a lower-income neighborhood (defined by block group) located 4 km from each other in the city of Phoenix. This is a substantial difference in a city where maximum summer temperature can reach 45^{o}C or more.
- Vegetation abundance mediates the relationship between socioeconomic status of neighborhoods and heterogeneity in microclimates. Higher-income neighborhoods were associated with increased vegetation cover, and vegetation, in turn, predicted average surface temperature with a high degree of accuracy. More abundant vegetation in affluent neighborhoods may be due to developers' decisions to build near agriculture or natural desert and to leave larger areas of open space within their borders. In addition, wealthier residents can afford to purchase and maintain greener residential landscaping. At a regional scale, all the variation in surface temperature explained by income and ethnicity was mediated through the amount of vegetation cover in the neighborhoods. For the eight individual neighborhoods that were investigated in detail, the neighborhood with the lowest air temperature had the greenest residential landscaping, the largest park, and consumed nearly twice as much water per household than the other neighborhoods.
- Feedbacks from neighborhood microclimates to human residents include exposure to extreme summer heat, especially during periods of heat waves. We developed a model of human thermal comfort applied to microclimate variables in Phoenix neighborhoods. Differences between neighborhoods in levels of human physiological response to climate were simulated by a computer human comfort model, OUTCOMES - OUTdoor COMfort Expert System (Heisler and Wang 2002). OUTCOMES estimates a human comfort index based on the energy balance of a hypothetical person given the weather data from a site and the site's surrounding solar and thermal radiative environmental fluxes. Heat indexes indicate people's level of risk for the occurrence of heat-related illness and mortality under varying environmental conditions. Lower-income inner-city neighborhoods and a middle income neighborhood on the urban fringe had higher heat stress index scores and experienced a greater number of heat stress hours during a three-month summer period in Phoenix. In the lower-income neighborhoods with the highest exposure, residents had the

least access to heat mitigation strategies - air conditioners, reflective roofs, and swimming pools.

- Data from high-spatial-resolution airborne sensors and high-temporal-resolution satellite sensors that are now available will help to further resolve historical and current complexities of social/biophysical interactions that produce variability in the urban heat island. Surface temperatures calculated from MODIS/ASTER Simulator (MASTER), Landsat Enhanced Thematic Mapper Plus (ETM+), and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) for the eight study neighborhoods were correlated using linear-least squares regression with Soil-Adjusted Vegetation Index (SAVI) values obtained from the ETM+ data. The SAVI was selected for use as it incorporates a correction factor for soil reflectance, which is a significant factor in arid environments due to the open canopy structure of most desert plant communities (Huete 1988). A strong negative correlation between surface temperature and vegetation density (R^2= 0.673) was obtained between 2000 MASTER surface temperature and 2000 ETM+ SAVI data at the neighborhood scale. Lower correlations of SAVI and ASTER surface temperature data were noted (R^2 ranging from 0.45 to 0.54). This is most probably due to the large seasonal differences between the ASTER, ETM+, and MASTER data. Acquisition of frequent surface-temperature and vegetation-density data using high-frequency, satellite-based instruments like ASTER and ETM+ would provide the opportunity to gain further insights into the seasonal dependance of socioeconomic trends observed in this study at the census-tract level.

Detailed studies of plant growth and climate-ecosystem interactions at small scales have focused on the thermal environment and effects of ground covers on vegetation performance. Not surprisingly, asphalt used in parking lots and streets creates a thermal environment that is very stressful for trees and shrubs, owing to very high rhizosphere temperatures (Celestian and Martin 2004). Mesiscape (turf lawn, large trees) microclimates are milder, with lower canopy vapor pressure deficits and lower canopy and soil temperatures, than xeriscape (gravel with drought-tolernat plants) or concrete and asphalt surfaces (Mueller and Day 2005). However, *Nerium oleander* growth was not consistently highest in mesiscape because cooler temperature in winter led to frost damage (Mueller and Day 2005).

<u>Surface mulches</u> are a common element of urban landscapes. Most municipalities within the CAP LTER area require application of surface mulches, like decomposing granite. to all bare landscape-soil surfaces for dust abatement in public areas. Landscape surface mulches include inorganic mulches, which are relatively stable and inert, and organic mulches, which may have ecological benefits such as organic matter enrichment. Effects of inorganic (decomposing granite) and organic (composted ponderosa pine residue and chipped urban tree trimmings) surface mulches on landscape water and nutrient cycling, productivity, and thermal environments were studied at the long-term experimental site at the Desert Botanical Garden (DBG). This experiment was superimposed on prior treatments manipulating irrigation and pruning.

Daytime surface temperatures in spring, summer, and autumn were lower, but mulch-soil interface temperature and albedo higher, for inorganic than for organic mulch. Similarly, belowground soil temperatures (5-10 cm) were more buffered by organic mulches than inorganic mulches throughout the 2004 growing season. To assess soil moisture availability, relative water content (RWC) was measured at dawn for leaves of *Nerium oleander* (oleander) and *Atriplex canescens* (quailbush) shrubs. Leaf RWC for *Nerium* was highest for pine bark and bare soil treatments and lowest for tree trimmings and decomposing granite. *Atriplex* were planted with and without irrigation; the irrigation-mulch interaction was significant for RWC of *Atriplex*. Soil respiration also showed interaction effects and a typical under-shrub enhancement, but was generally enhanced with organic mulch. *Nerium oleander* and *Leucophyllum frutescens* (Texas sage) growth and volume were not affected by the mulch, but instead showed continued response to former pruning and irrigation treatments, indicating that the legacy of pruning, a frequent human activity in the desert Southwest, persists for at least a year following cessation of the activity.

Arbuscular mycorrhizal (AM) fungi have been the subject of CAP investigations in the BIODIV IPA, but because these organisms strongly affect NPP, a project to evaluate Growth Effects on *Encelia farinosa* (Brittlebush) due to Suppression of Arbuscular Mycorrhizal Fungi at an Urban and a Desert Site has been initiated in CAP2. Little is known about the impact of AM fungi on NPP in urban areas. The productivity of *Encelia farinosa* (brittlebush), which is common in both urban and desert areas, is being measured with and without fungicide treatment to determine the influence of AM colonization on growth. The fungicide Benomyl (methyl-1-(butyl-carbamoyl)-2-benzimidazole) suppresses colonization of roots by AM fungi; thus, brittlebush growth should be strongly affected by the fungicide when AM colonization is important and little affected when it is not. Growth of plants growing at two long-term experimental plots—DBG in Phoenix (urban) and at Usery Mountain Park (UMP) in Mesa (desert)—is being measured following fungicide treatment (with half of the plants remaining as a control group). This project has been underway since June 2004, but data are still being analyzed.

Water Policy, Use, and Supply (WATER)

Decision making about water is the primary focus of ASU's new Decision Center for a Desert City, which is interacting closely with CAP LTER personnel. In addition, several projects in the FLUXES IPA are related to the WATER IPA because of a focus on water quality and aquatic biogeochemistry. Although these projects are described elsewhere, our intention is to work toward integrating these areas through improved understanding of Phoenix metro's hydrologic budget. Here, we post findings from two pilot projects and three broader-scale analyses completed during 2004-2005.

Surface Water Distribution and Aquatic Biogeochemical Processes in the CAP LTER. Although the rivers of Phoenix were once perennial, upstream dams have resulted in no instream flow in the Salt since 1938; tributaries to the Salt are intermittent and dammed as well. As the city has grown, many lakes fed by canals and groundwater have been created for recreational and aesthetic purposes. In this project, the current state of GIS information from governmental planning organizations was assessed, and ASTER data were used to spectrally identify permanent lakes in the Phoenix metropolitan area. The analysis revealed extensive errors and misclassification in existing data layers, and found a total of almost 1,000 lakes in the Phoenix metro area, nearly all of which have been established since 1950 (Larson and Grimm, in preparation). Moreover, extensive modification of small streams and mid-sized rivers in the region, coupled with lowered groundwater tables, has resulted in large shifts in the hydrogeomorphic template of urban streams such that they likely no longer function in similar ways to their non-urban counterparts (Grimm *et al.* 2004).

As part of the City of Phoenix and Arizona State University GPS Data Collection Pilot Study, an analysis of construction of water infrastructure for Phoenix between 1953 and 2003 (Burns and Kenney 2005) shows clearly how water infrastructure followed transportation infrastructure in encouraging the sprawling growth of Phoenix. Long water mains were built following major arterial streets, often allowing the leap-frog growth (and subsequent infill) that characterizes Phoenix.

The Channel Morphology and Instability along the Urban Fringe project assessed the danger of flooding on the Hassayampa River, and documented the natural hydrologic processes that maintain the current geomorphic structure. A full record of aerial photography spanning the years 1934-2004 was compiled and documented. Specific regions of the river channel and surrounding banks showed significant geomorphic change over the time period of the aerial photography. In downstream reaches, agriculture has been the primary mode of change, but all geomorphic change in the upstream reaches was flood-related. Flood-frequency analysis is compromised by the short record; but the Hassayampa has seen very mild storms with the exception of the time between 1970 and 1992 when there were significant floods roughly every five years (1970, 1978, 1980, 1984, and 1992).

As development planning continues to expand beyond the current bounds of greater Phoenix, previously unaffected watersheds are being encroached upon, and the Hassayampa River, located at the western edge of the CAP LTER study area, is no exception. Arizona Department of Water Resources data indicate the geographic extent of proposed development with >200,000 new homes along the Hassayampa River. The original hypothesis that this watershed would have high flood hazards to residential development appears false at the conclusion of this preliminary research, because the Flood Control District of Maricopa County has strict regulations requiring flood control structures such as retention basins. Combined with gravel mines in the river bed, retention basins will contain most floods up to the currently estimated 100-year flood. Thus, future residential developments are not in great danger from flooding from the Hassayampa River. Initially, construction will create a huge influx of sediment to the system but, when the development is complete, sediment input to the system will shut down owing to flood-control structures, and this loss of sediment will likely cause stream incision. Riparian 'restoration' or non-structural flood management may partly ameliorate or at least defer that inevitability.

<u>The Effects of River Modification on the Soil Seed Bank of the Salt River, Arizona: A Case Study of an Arid Region River.</u> Riparian community structure and function along urban arid-region rivers is virtually unexplored in the ecological literature. The purpose of this investigation is to determine the effect of disruption of river continuity and river-floodplain connectivity by water diversion on the seed bank of a highly urbanized arid region river (the Salt River in Phoenix), and how this altered seed bank is affected by the return of water from urban tributaries, which restores some river-floodplain connectivity. The composition of the soil seed banks was compared to the aboveground vegetation within and between reaches of the Salt River which exhibit three different levels of water availability and thus three levels of channel-floodplain connectivity: perennial with moderate connectivity, intermittent with low connectivity, and dry with no connectivity. Sites were classified into four vegetation/water availability patch types that represent the dominant conditions. In each patch type, replicate soil cores were taken for soil seed bank measurement and percentage cover of all herbaceous species was visually estimated. Woody species were sampled once for presence/absence. Significant findings of particular importance to restoration success include the identification of several plant species that were previously uncollected or rarely collected along the Salt River, as well as the low soil seed bank richness compared to reference rivers. All field sampling has been completed, but identification of unknown species is still underway.

Material Fluxes and Socioecosystem Response (FLUXES)

The <u>Aquatic Core Monitoring</u> work compares native desert and urban stream ecosystems by examining differences in concentrations of dissolved organic carbon (DOC), nutrients, and conservative ions among desert stream/river sites that are unregulated (upstream of the metro Phoenix area) and sampling sites where both water flows and water quality are regulated and highly modified by the urban environment. The five sampling sites (three upstream, two downstream of the urban area) are visited and sampled 6-12 times per year, to capture any seasonal and, whenever possible, flow-related variations in water chemistry.

Results from CAP1 have been extensively analyzed and are in the final stages of preparation for publication (Edmonds *et al.* in preparation). Water retention by the city was particularly high during the severe drought of most of the past seven years. Hence, climate-induced variation in water chemistry was only weakly related to river hydrology during these dry periods. A major objective was to identify how patterns in water chemistry upstream versus downstream of the city have changed, and the possible implications these changes might have for biogeochemical cycling. The Phoenix metropolitan area routes water through hundreds of urban flowpaths, including canals, pipes, and modified stream channels. These flowpaths coalesce downstream, but with a substantial reduction in water volume (<10% of the original amount). Climatic variability in the desert Southwest has encouraged extraordinary measures for reusing and retaining water for irrigation of lawns, crops, and as a drinking water source, which eventually leads to evaporation of the water. Therefore, the city is very good at retaining water, particularly during extended drought periods (decades-long), essentially acting like a huge evaporating pan. This manipulation of water concentrates dissolved materials. A comparison of surface water input and output loads (total mass) to and from the city found significant retention of DOC and total dissolved salts (TDS). The percentage retention of these two components was lower than the water retention value, which indicates that water accumulated DOC and salts as it was routed through the city. And while nitrogen (N) and phosphorus (P) stream loads were higher downstream of the city versus upstream, N loads were less than double that of upstream, not an order of magnitude higher as with the concentration data.

Downstream river water concentrations were much higher than those found upstream of the city (Edmonds *et al.* in preparation). Water retention within the city was higher than the retention of salts, DOC, total dissolved nitrogen, and total phosphorus indicating that these constituents accumulated in the water as it moved through the city. These accumulated constituents are most likely from three sources: 1) urban surfaces which experience high rates of atmospheric deposition of N and carbon (C) and are likely to supply high nutrient concentrations to local waterways; 2) groundwater—from the use of fertilizers and the evaporation of water during irrigation; and 3) the disposal of human food and waste, via highly concentrated waste water treatment plant (WWTP) effluent, which is released into the river system. It seems that human activity and decision making has assumed primary control over variation in stream-water chemistry. This control was more pronounced during extremely dry climatic conditions, establishing a feedback between environmental change and ecosystem engineering by humans.

Another research objective was to link changes in urban ecosystem management or structure with changes in downstream-water chemistry. There was a decline in N concentrations and loads in the water exported from the city, suggesting a change in the functioning of the urban ecosystem. This decline coincides with the increase in the use of Central Arizona Project canal (Colorado River) water, but is most likely due to a reduction in N loads from the WWTP when tertiary treatment began in 1997. The pattern of reduced export was also found for P and conservative ions (i.e., not biologically or chemically reactive), suggesting that these declines are most likely a combination of the current drought conditions and greater awareness of water quality issues by city managers. In summary, patterns in upstream-downstream-water chemistry are related to the functioning of the Phoenix metropolitan area as a whole. Stream biogeochemical cycling has been significantly altered by the presence of this urban center. The city is exporting more biologically reactive ions than enter and retaining conservative ions. Climatic variability has a strong influence on urban water chemistry on the decadal scale, but less of an effect at shorter time periods.

Although drought conditions remain in the forecast for the Southwest, winter-spring 2005 was a relatively wet period, affording us an opportunity to examine flood chemistry of the mainstem Salt River (which, in spring 2005, actually was a river) and other important water sources for Phoenix. The analysis of Water Chemistry in Local Rivers After the 2005 Spring Rain Events reveals that variations in major element chemistry correlate with high discharge events along the river system, whether natural or human induced. Chloride, sulfate, magnesium, potassium, and sodium concentrations generally decreased from early January to early February, and exhibited synchronous variations. In contrast, concentrations of calcium increased over time. Concentrations of nitrate increased initially and then fluctuated slightly around 2 ppm. These preliminary findings were intriguing enough to encourage continued longitudinal sampling of the major river system (with the Salt River now having reverted to its urban "lake" status). Analyses at low flow using a complete suite of trace elements suggest that the different sources of water to the Phoenix metropolitan area have distinct "source fingerprints" which will be useful in identifying possible anthropogenic, water management and natural inputs to the Salt River. Identifying the source of water during discharge events and correlating that information with known chemical fluxes of metals and nutrients during those times will establish a chemical fingerprint of different water-soil/rock interactions.

The Nutrient Transport and Retention in Urban Watersheds project focuses mainly on nutrients that are potentially limiting to aquatic production or are potential pollutants associated with aquatic eutrophication (e.g., N, P, and DOC). During 2004-2005, we focused on analysis of results from several-year studies of Indian Bend Wash (IBW), a small, highly managed urban lake-stream system in Scottsdale (Roach *et al.* in review), completed experiments for the Lotic Intersite Nitrogen eXperiment (LINX2) project, and completed an analysis of spatial heterogeneity of storm-mediated export of nitrogen from urban catchments (Lewis and Grimm in review). Findings from the IBW study are as follows:

- The ability of this lake chain to retain nutrients was examined. Although lakes and streams did behave consistently, alternately acting as sources or sinks for a wide variety of limnological variables, the wash as a whole periodically exhibited significant processing of NH_4^+, NO_3^-, soluble reactive phosphorus (SRP) and DOC. On balance, the wash tended to be a sink for SRP and a source for NH_4^+ and DOC. The processing of NO_3^- was less predictable. The wash alternately acted as a source and a sink for this nutrient.
- The degree to which a variable's dynamics are synchronized with other points in space is an indication of the scale of the driver producing the observed variability. The synchrony of nine limnological variables measured at the inlets and outlets of the lake chain were used to evaluate the relative importance of broad-scale climatic drivers and local processing in IBW. All variables showed a remarkable degree of synchrony which declined as the distance between sampling points increased. Temperature dynamics were the most synchronous, indicating the strong effect of climate. Surprisingly, nutrient dynamics were also highly synchronous. This was attributed to the strong effects of management decisions about the mix of water sources used to maintain flows through the wash. As the relative proportion of different water sources diverted into the wash varied, so was the water chemistry throughout the wash. As a result, NH_4^+, NO_3^-, and SRP dynamics were highly synchronous. Linear regression was used to examine the effect of distance, measured as the thalweg length, area, and volume between sampling points, on synchrony. The synchrony of all variables declined with distance, but this decline was most rapid for NO_3^-, suggesting that NO_3^- dynamics were strongly affected by internal processing.
- A series of experiments was conducted in artificial lakes, channelized stream segments, and turf-dominated floodplain of IBW to determine which patches were important sites of

denitrification and to learn what factors controlled potential rates of denitrification (Roach and Grimm, in preparation). Dentrifying enzyme activity measured on sediments collected from eight lake and six stream segments as well as soil samples from eight floodplain transects demonstrated that mass-specific potential denitrification rates were significantly higher in lakes than in streams or floodplains. Nutrient limitation bioassays revealed that NO_3^- limited denitrification in lake sediments whereas in floodplain soils the process was limited by the prevalence of anaerobic conditions created by water additions. Although rain is rare in the desert, irrigation is common and thus annual denitrification in the floodplain can be substantial. Because lake water NO_3^-–N concentration often exceeds 1 mg^{-1} L^{-1}, the finding that NO_3^- limited denitrification in the sediments was surprising. However, further experiments using intact cores demonstrated that it was not so much the availability of NO_3^- in the overlying water as the rate at which it diffused into the sediments that limited denitrification in the lakes.

- Although nutrient limitation was not previously demonstrated to occur in IBW except during summer low flow, when P was limiting (Goettl and Grimm, in revision), a higher-frequency (especially after floods) analysis of nutrient limitation to phytoplankton showed frequent shifts from P limitation, to N limitation, or to co-limitation both in time and in space. Thus, the complexities of water addition to this system (by natural floods or human-mediated additions) drive the dynamics of NPP through alterations in nutrient limitation.

LINX2 experiments, in which $^{15}NO_3$ is added continuously to a stream over 24 h, were conducted in IBW as well as in Highline Canal (a small, cement-lined canal with very high flow velocity, high NO_3 concentration, and no riparian vegetation). LINX experiments were supplemented with short-term nutrient addition experiments and measurement of natural decline in nitrate and ammonium, in order to develop a preliminary picture of the capacity of urban streams to reain nitrogen. We found that, in comparison to their non-urban counterparts in the Southwest, urban streams had longer uptake lengths and lower uptake velocities, even at comparable discharge and nitrate concentration (Grimm *et al.* 2005). Thus, these systems are impaired in terms of their ability to retain N, probably owing to the combined effects of hydrogeomorphic modification, reduced primary production, and higher nutrient and toxic loads (Grimm *et al.* 2004, Grimm *et al.* 2005).

Changes in and the spatial structure of nutrient storage in terrestrial components of the CAP region have been investigated in soil studies conducted as part of the Survey 200. Much of the past year has been spent conducting analyses of the excellent spatial data set from the survey conducted in 2000. In terms of spatial structure, analyses for inorganic soil N showed that both NO_3-N and NH_4-N concentrations were markedly higher and more heterogeneous amongst urban compared to desert soils. Regional variation in soil NO_3-N concentration was best explained by latitude, land use history, population density, along with percent cover of impervious surfaces and lawn, whereas soil NH_4-N concentrations were related to only latitude and population density. Within the urban area, patterns in both soil NO_3-N and NH_4-N were best predicted by elevation, population density and type of irrigation in the surrounding neighborhood. Spatial autocorrelation of soil NO_3-N concentrations explained 49% of variation among desert sites but was absent between urban sites (Hope *et al.* in press *b*).

Over the last 12 months, the Soil Working Group conducted further analyses of soil N and also total soil C using a Bayesian approach (Oleson *et al.* in review). This confirmed that the spatial autocorrelation between desert sites is absent in the urban areas. Most recently, hierarchical spatial (Bayesian kriging) modeling of soil N, C and extractable P (Majumbar *et al.* in review) has found six important response variables (slope, elevation, land use type, percent of impervious surface area, percent of lawn cover and whether a site was ever used for agriculture).

These can be used to predict soil nutrient concentrations at unsampled locations, hence allowing accurate estimates of total soil nutrient pools across the region. Concentrations of total N, organic C, and P in soils across the CAP region all increase with increases in urbanization covariates. Ongoing research over the next 12 months will use these techniques to develop accurate estimates of total soil nutrient pools across the CAP region. These techniques will also enable future work to investigate directional gradients in soil nutrient concentration surfaces and to find the second order behaviour of these surfaces, which could then be used to predict the consequences of future urbanization and socio-economic changes on the soil nutrient resource of the region.

Several independent lines of evidence including those described above suggest strongly that the main effect of urbanization on soil N and organic C storage has been an increase (Zhu *et al.* in press, Hope *et al.* in press b, Jenerette *et al.* in press b, Lewis *et al.* in review). While conventional wisdom holds that both agricultural and urban land uses should *decrease* soil C, it is not surprising that growing crops or lawns with attendant irrigation and fertilization regimes in a desert environment has the effect of increasing soil nutrient and carbon stores. Estimates from weighted summation of patch-specific analyses of soil N species suggest that N is elevated not only in urban environment, but also in the nearby desert soils (Zhu *et al.* in press), likely a consequence of atmospheric deposition of N (see below).

<u>Points, Patches and Regions: Scaling Soil Biogeochemical Patterns in an Urbanized Arid Ecosystem</u>. Because urban development is a phenomenon occurring at multiple scales, ecological consequences of urbanization will likely differ between individual patches and the entire metropolitan region. To investigate such changes we conducted spatially explicit surveys including three dominant land-use types in this region: native desert, agriculture, and mesic residential. These data were combined for analysis with the previously collected Survey 200 (year 2000) samples. A landscape scaling approach was implemented to compare the dependence of soil variability on the sampled extent and the uncertainty associated with scaling from points to patches, land-use types, and the Phoenix metropolitan region. The multiple-scale analysis of soil properties showed that variation in total soil nitrogen, soil organic matter, and $\delta 15N$ content of soils differed significantly between patch and regional scales. The majority of variation in the urbanized patch types was exhibited between patches while for the native desert the majority of variation was observed within individual patches. These differences show the impact of urbanization on scaling relations. Overall, urbanization in this region appears to have increased soil organic matter by 44%, total nitrogen by 48%, and has elevated $\delta 15N$ by 21%. A paper based on this work has been accepted for publication (Jenerette *et al.* in press b).

Soil is the largest recipient system of toxic and nontoxic trace elements in most terrestrial ecosystems. Investigating the spatial distribution of trace elements in soils can reveal human influences on terrestrial ecological systems, and may influence other aspects of urban ecology as well as decision making. In CAP2, we have expanded our soil analysis <u>Survey 200</u> to include analysis of trace elements and metals. By the end of May 2005, ~400 soil samples from the 2005 <u>Survey 200</u> sampling were obtained by the survey crew, one top soil and one deeper soil sample for each point. Sampling for metals analysis entails use of plastic sampling and processing equipment and grinding of sived samples with an agate mortar and pestle; elemental analysis and sample preparation are being carried out using the High-Resolution Inductively Coupled Plasma Mass Spectrometer (ICP MS, Finnigan Element II), permiting very low detection limits for trace elements in soil samples. Preliminary results from methods-development work done on archived samples from the year 2000 survey indicate that concentrations vary among samples, and that heavy metals such as Pb (lead), Cu (copper), Zn (zinc) and other trace elements such as Cr (chromium) and As (arsenic) tend to be more abundant in soils from industrial areas, major roads and highways. Surprisingly, the soil sample from a residential area showed relatively high contents of Pb and Zn. The agricultural soil sample had the highest concentration of Cr out of the 10 samples selected. These preliminary results suggest that we will learn much about spatial heterogeneity of toxic and contaminating material distributions in soils; eventually we plan to relate these distributions to socioeconomic spatial structure.

Beginning with the mass balance for N (Baker *et al.* 2001), the Nutrients and Data Synthesis: Mass Balances project has the goal of developing whole-ecosystem mass balances for the city. These mass balances provide an excellent frame of reference against which to compare results from patch-specific or long-term monitoring studies; for example, the finding that N has accumulated in the metropolitan area soils (Zhu *et al.* in press) and in groundwater (Baker *et al.* in press) is consistent with the mass balance results showing an overall ca. 14 kg ha^{-1} y^{-1} accumulation of N (excess of input over output). This past year also saw completion of a preliminary estimate of the salt balance for CAP; findings indicate an accumulation of salt in both groundwater and soils, especially in agricultural regions. This interesting result recalls the ancient Hohokam civilization, which was said to have "collapsed" in part due to salinization of soils from long-term crop irrigation. CAP LTER researchers are interested in determining whether modern Phoenix can be more resilient in the face of this sort of ecosystem change.

Soil sampling and characterization in the North Desert Village Experiment—Soil is undertaken to understand the effect different types of residential landscaping (commonly found across the CAP ecosystems) on soil nutrient pools and nutrient dynamics. Baseline sampling to physically and chemically characterize the soil resource across the entire NDV development was carried out over the last 18 months. This included a) soil coring to a depth of 30 cm and b) excavation of soil pits by the local branch of the Natural Resources Conservation Service (NRCS). In the latter, a detailed profile description was made and samples taken from every distinct soil horizon. These samples are in the process of being analyzed at the NRCS laboratory. Analysis of the soil core samples is currently ongoing by CAP personnel.

Atmospheric deposition in the Phoenix metro area has been monitored since the inception of CAP; however, through work with fluid-dynamics modelers and atmospheric chemists we have begun to modify our long-term monitoring strategy. Furthermore, we were successful in obtaining funding for a new project to study the effects of the urban atmosphere (especially inorganic N and organic C from fossil-fuel combustion and, in the latter case, cooking operations) on desert soil-microbe-plant processes (Grimm *et al.* 2005).

In the long-term Atmospheric Deposition Program, there have been three main areas of effort over the last 12 months. 1) Refining and improving the modeling work to predict N deposition at the regional scale over the CAP region. Using a combination of diagnostic and Models-3/CMAQ simulation modeling annual estimates of NOx-derived dry deposition fluxes were derived and the role of urban vegetation on NOx-derived dry deposition fluxes was investigated. Therefore a new land cover classification and updated remote sensing derived land cover data were introduced in the models to account for spatial extent and heterogeneity of urban land cover. Adjustments were made in the deposition velocity calculations to consider the adaptation of local plants to the environmental conditions of Central Arizona. According to the simulations 25 % of the NOx derived dry deposition fluxes in the urban area were deposited on vegetation. When urban vegetation was excluded from the simulations NO2 deposition was reduced by 57 % because of the significantly lower deposition velocities of impervious compared to vegetated surfaces; nitric acid deposition was relatively unchanged. Using input data from urban air quality monitoring sites, hourly NO and NO2 dry N deposition fluxes were simulated for the entire year 1998 to ~6 kg ha-1 yr-1. Dry deposition declined during the summer months, due to lower pollutant concentrations and temperature-induced closure of the plant stomata during afternoon hours. 2) Development of alternative techniques for measuring atmospheric deposition. Work has been ongoing to develop more sophisticated and direct methods of measuring dry deposition of various ionic species, suitable for use in the urban environment. We have constructed filter banks to sample particles of different sizes (<2.5 μm, 2.5 μm<d_p<10 μm, and >10 μm) that, when combined with eddy-correlation data, can provide estimates of dry deposition, and have successfully tested these samplers at a broccoli field near Phoenix. Filter banks samplers are currently being emplaced along with complete weather stations at new, long-term fertilization experimental sites (see below). Also, we have worked out methods for analyzing nitrate, ammonium, total P, and total N associated with these samplers. 3) Continuous long-term monitoring using simple wet-dry buckets has been ongoing, but scaled down from the eight collectors used in CAP1. Over the past year we reduced the monitoring network to just three collector locations – at the "Phoenix Supersite" an urban core site and the location of Arizona Department of Environmental Quality's main air-quality monitoring instrumentation, and two desert sites to the west (upwind) and east (downwind) of the metro Phoenix area. Statistical analysis of wet and dry deposition data collected from original monitoring network is ongoing (Grossman-Clarke *et. al* 2005).

Particulate material is monitored by state and local agencies because of its relevance to human health and allergy. CAP researchers compared particles from urban fringe and desert locations, finding that the biological fraction of the air-bound particulate pool was consistently higher in the city, although both sites contaned allergenic organisms (Boreson *et al.* 2004).

The new Ecosystem Response to Inorganic N and Organic C from the Urban Atmosphere project (Grimm *et al.* 2005) will form the foundation for our long-term, crossed N and P fertilization experiment. Sites have been selected, plots have been marked, initial soil nutrient pools have analyzed, atmospheric deposition monitoring has begun, and fertilizations will begin in November 2005. Sixteen sites (to be reduced to 12 for fertilization) are at upwind, core, and downwind positions (roughly SW to NE transect across the metropolitan area).

Human Control of Biodiversity (BIODIV)

Biodiversity research, employing both monitoring and experimentation, has focused upon arthropods, birds, mycorrhizal fungi, and vascular plants. In the Long-Term Monitoring of Ground Arthropod Biodiversity study we examine how the ground arthropod community of the Sonoran Desert has changed as the Phoenix metropolitan area has grown and created a diversity of habitats for arthropods. Despite their global ubiquity, surprisingly little is known about how arthropods respond to urbanization, even though urbanization has been identified as one of the leading causes of declines in arthropod diversity and abundance. Although there have been some studies of specific taxa (primarily pest species) in urban settings, these studies were primarily concerned with focal insect species rather than entire arthropod assemblages. Urbanization may have a variety of effects on the local arthropod assemblages, based upon conversion of indigenous habitat to anthropogenic habitat. If arthropods respond to habitat structure, then we predicted differences in species assemblages among different forms of urban land use (residential, industrial, agricultural, and remnant desert), which differ in habitat structure. Communities in residential, industrial, and agricultural land were initially predicted to be subsets of desert (indigenous) communities. We have sampled ground arthropods in metropolitan Phoenix using 500 ml pitfall traps. This year arthropods were collected at 21 sites, on transects of ten traps each. Sites included the following landscape types: agriculture, commercial/industrial, residential mesic, residential xeric, desert parks, outlying desert. Traps were unbaited and left open for three days. In the laboratory specimens were sorted, identified (usually to family or genus) and stored in glass jars.

Continuing analysis in 2004-2005 of the long-term dataset revealed that irrigation seems to have a primary effect on the urban arthropod community. In recent years the two heavily irrigated landscape types (agricultural fields, mesic residential yards) have supported the largest number of arthropod taxa and the largest number of individuals. These two landscape types also featured the greatest number of taxa significantly associated (by indicator species analysis) primarily with one type, and stood apart from other types in ordination analyses. Desert sites and desert parks contained a common suite of taxa not found in other areas, although the overall taxon richness and abundance was low. Xeric residential yards and commercial sites had intermediate arthropod abundance, but no taxa were primarily associated with either landscape type. Overall, there two general patterns stood out in the data: 1) irrigated sites stood apart from the others in terms of abundance, richness and closely associated taxa, and 2) desert sites had low abundance but several taxa not found in urban sites, indicating that communities at non-irrigated urban sites do not resemble undisturbed desert communities.

The goal of Point Count Bird Censusing is to study the patterns in bird species diversity, abundance and distribution over time and space, and the processes behind these patterns as a result of urbanization. Ongoing since October 2000, this study is documenting the abundance and distribution of birds at 51 sites in four habitats: Urban (18) Desert (15) Riparian (11) and Agricultural (7). The 40 non-riparian sites are a subset of the 200 Survey locations. We are using point counts to survey birds four times a year (January, April, July and October). During each session each point is visited by three birders who count all birds seen or heard for 15 min. Our goal is to study how different land-use forms affect bird abundance, distribution and diversity in the greater Phoenix area in order to predict and preserve high bird species diversity as urban development is proceeding. We have now just completed three years of monitoring and are also beginning to see some of the sites changing due to new urban development. We have determined that seasonal and interannual variation in bird species richness and abundance is dampened at urban sites relative to desert or agricultural sites. This novel finding suggests new avenues for studying effects of urbanization. Conventional understanding of urban systems is that diversity is reduced and abundance is increased relative to nearby wildlands. Our work suggests makes the story more complex, suggesting that urban environments might buffer environmental extremes for some native species. We are still determining the mechanisms underlying this finding, but growing evidence suggests that irrigation and food provisioning play a significant role (Shochat 2004).

Geostatistical methods provide novel approaches for analyzing spatial patterns of ecological phenomena. The objective of the Spatial Interpolation of Avian Counts was to create an interpolation technique for visualization and quantification of avian distribution patterns throughout the entire CAP LTER study area. We employed two kriging methods (ordinary and indicator) in our analyses of three bird species known to differentially occupy the urban to rural gradient within the Phoenix metropolitan area and surrounding desert (Arizona, USA). Ordinary kriging interpolates values between measurements; however, it requires normally distributed data, which is commonly invalidated in ecological censuses. Indicator kriging is not able to produce numerical predictions of measurements, but has the advantages of not requiring normality and requiring fewer decisions to be made. Avian census monitoring was conducted seasonally for two years at 40 sites encompassing the Phoenix metropolitan and surrounding desert. We aggregated these counts and selected three resident bird species to exhibit how these ecologically distinct avian species differentially occupy the urban to exurban gradient through the process of interpolation. Each of these species exhibited strong deviations from normality due to many observations of zero or one. Given the skewness of the data, we anticipated that indicator kriging would be a more appropriate method of interpolation. However, we found that both methods adequately captured spatial distribution of the three species and are sufficient for creating distribution maps of avian species. With additional census monitoring, kriging can be used to detect long-term changes in population distribution of avian and other wildlife populations.

Our major goal for the Arbuscular Mycorrhizal (AM) Fungal study was to compare AM fungal community structure in the Phoenix urban area with the surrounding desert and to examine the influence of introduced exotic landcape plants on AM fungi. During the past year we have focused on collecting data from 30 additional Survey 200 sites**:** Ten sites from the Sonoran Desert with soil samples collected from native plants; 10 sites from the Phoenix metopolitan area where soil samples were collected from native plants; and 10 sites from the Phoenix metropolitan area where soil was collected from exotic plants. Our research questions include: Does AM fungal diversity and species composition differ between arid urban areas and the surrounding desert? Are there differencs in AM fungal diversity and species composition associated with native and exotic plants in urban areas? Are there differences in the AM fungi associated with native plants located in urban landscape in comparison to native plants located in the desert? Soil samples were collected from three woody plants at the thirty Survey 200 sites and used to set up trap pot cultures in the greenhouse (used to stimulate spore formation). Spores are extracted and identified. The mean number of species per site and mean number per tree and relative frequency of each species will be determined. Statistical analysis will be used to determine differences between urban and desert sites and between native and exotic plants. AM fungal species identification has been completed for 17 sites. Samples have been processed for an additional seven sites and with the final step of spore identification required. Pot cultures have been grown for the remaining sites but samples need to process and spores identified. Comparisons between arbuscular mycorrhizal fungal community in the Phoenix metropolitan area and the surrounding desert.

Our preliminary results indicate that the AM fungal community differs between urban and desert areas. Almost twice as many total AM fungal species were detected in the desert in comparison to urban areas. There was also a greater mean number of AM fungal species per woody plant sampled at desert sites in comparison to urban sites. There was a significant overlap in the species composition between desert and urban sites with all species detected in the urban areas also present at desert sites. The most frequently detected AM fungal species were similar in urban and desert sites. Initial analysis of AM fungi associated with two native plants, *Larrea tridentata* (creosote bush) and *Parkinsonia* spp. (palo verde), found growing at both urban and desert sites found no differences in the mean number of AM fungal species detected per plant. We are currently examining community structure associated with exotic plants.

Short-term experimentation has been used extensively in BIODIV research to study urbanization influences on populations, communities, and species interactions (Shochat *et al.* 2004, Faeth *et al.* 2005). Our trophic structure and dynamics experiment generated preliminary data indicating that diversity and abundances of arthropod herbivores, predators and parasites differed dramatically among urban and desert sites and with season. Furthermore, top-down effects, especially from avian predators, were shown to be more pronounced in mesic urban habitats, whereas bottom-up forces (e.g., plant resources) dominate outlying natural deserts (Faeth *et al.* 2005). CAP LTER-leveraged funding has been obtained to expland research on the effects of urbanization on trophic interactions (Faeth and Sabo, NSF Ecology 2005). To the extent possible, research sites are being located near to the new sites of the long-term fertilization experiment (see FLUXES).

Survey 200 findings show that land-use changes brought about by urbanization increases spatial heterogeneity of plant diversity, soil nutrients, mycorrhizal diversity and deposited pollen.

Initial spatial modeling of the Survey 200 data revealed that for plants, the replacement of Sonoran Desert vegetation with largely exotic species has resulted in a much greater variation in plant genera from site to site (ß diversity), as well as higher total diversity (γ diversity) across the whole city and region (Hope *et al.* in press *a*). However, urban landscapes do have similar average generic plant diversity to the native desert vegetation they have replaced. Personal and institutional landscaping choices (i.e., additions of non-native plants, water and fertilizer) have modified traditional ecological resource availability-diversity relationships. Rather than natural (water and nutrient) resource supply, plant diversity is positively related to economic resources (median family income in our analysis). This "luxury effect" means that as people's economic wherewithal increases, they create landscapes with higher plant diversity. This finding and the absence of spatial autocorrelation of both plant diversity (at the generic level) and soil inorganic N (see previous) between urban sites (Hope *et al.* in press *b*) has led us to conclude that urbanization and development disrupt natural, geomorphically controlled patterns in Sonoran Desert plant communities and soils. Instead, ecological variables (and by inference, processes) are determined by local factors related largely to human management practices, which tend to vary with the specific site (Hope *et al.* in press *a*).

These findings at the broad, whole-ecosystem scale have been confirmed at the neighborhood scale as well. In a study comparing vegetation richness and abundance across 16 neighborhoods surrounding the parks of the <u>Ecological and Social Interactions in Urban Parks</u> project, median family income explained 86% of the variance in neighborhood vegetation richness. Vegetation abundance was explained primarily by time since disturbance (median year of neighborhood development) (Martin *et al.* 2003). Based on these and other findings, CAP is mounting many efforts that are focused at this neighborhood scale, including PASS (see LULCC), North Desert Village Experiment, Urban Parks, and Biodiversity and Neighborhood Social Variation projects.

The <u>North Desert Village Experiment</u> was launched during year 1 of CAP2. Most of the past year's work efforts have been directed toward installation of irrigation and landscape plantings, but there has been one major development. During planning for the experiment residents expressed concern about the inclusion of spiny plants (especially cacti and succulents) in our planned treatment design and the potential hazard to children. This was solved by researchers caging such plants. However, the problem led to the concept of adaptive experimentation whereby researchers modify aspects of the treatments during the progress of the study, where necessary (see, e.g., Cook *et al.* 2004). Another example of this is that residents will be allowed to modify the plantings directly around their own homes. This will allow researchers to study how people living on the experiment interact with it, while still preserving the original planting patterns in the communal areas. When residents turn over (i.e., rental occupancy changes) any landscape modifications will be removed and the original treatment restored.

<u>North Desert Village Experiment—Monitoring Human-Environmental Interactions</u>: The North Desert Village social science team studies reciprocal relationships between humans and the different types of landscaping. The study includes a structured survey, direct observations of behavior, and qualitative analysis of recorded and transcribed discourses intended to elucidate the inter-relational effects of environmental values, landscape preferences, social interaction and behavior before treatment and at continuous periodic intervals after experimental treatment. Results will further scholarly understanding of human interaction with small scale environments, such as backyards and neighborhoods and inform local water managers and policy analysts of human response to landscape treatments with different water requirements. This study contributes to our understanding of information feedback between non-human and human components of ecosystems. The structured survey includes 1) Likert scale ratings of computer-generated pictures of the various landscapes, 2) Likert scale evaluations of environmental

statements using the widely used protocol developed by Dunlap *et al.* (2000) supplemented by statements specific to metropolitan Phoenix, 3) identification of 10 local plants and 6 birds by name and habitat, 4) questions about landscape-based activities in the past week, 5) rankings of satisfaction with social interactions with neighbors and frequency of interaction, 6) histories of residence, and 7) respondent gender, education level, age, and ethnicity. Adults in all 30 households (four experimental treatment blocks and one control) were interviewed prior to landscape manipulation and once every two years subsequently. Direct observations of behavior include spot-check time allocation sampling of group composition, area of activity (yards, streets, common areas), and a suite of coded activities ranging from children playing to gardening. This sampling is supplemented by trace behavior surveys (observations of past activities that leave a behavioral signature, such as watering or gardening).

All baseline (pretreatment) data collection has been completed. Between May 2004 and May 2005 we conducted interviews with adults in all 29 households (one house is permanently vacant), plus new adults who moved in subsequent to the initial interviews. All of the structured survey data have been entered in SPSS format and stored on the CAP LTER server. A complete behavior sample was completed during the past year. These data have been entered into an Access database and are stored on the CAP LTER server. Audio recordings of interviews are stored on the CAP LTER server and have been partially transcribed. We have completed a preliminary quantitative and qualitative analysis of structured survey data, discursive data, and behavior data.

Most survey respondents in our study preferred water-intensive landscapes for their home, in all but one case they chose landscape with at least some lawn (oasis or mesic) for their primary preference. Residents with stronger environmental attitudes were more likely to choose the oasis landscape to minimize turf area, citing environmental reasons, but environmental values did not appear strong enough to lead respondents to prefer xeric landscapes. Many respondents expressed aesthetic appreciation for desert scenery in general, but did not prefer desert or xeric landscapes for their homes. In analyzing discourses from open-ended questions and other comments made by residents, it was determined that cultural constructions of “home” and “family” are major factors influencing landscaping preference. There is a strong perceived connection between green landscaping and idyllic families. The number of young children in the household, defined as children between the ages of 0 and 6, was significantly correlated with ratings for mesic backyards. Other findings include:

- Social networks are perceived as stronger by respondents who spend more time engaged in outdoor activities.
- Ecological knowledge was not correlated with environmental concern or landscape preference.
- Landscape preferences were influenced by gender, with women showing a stronger aversion to arid landscapes.
- Outdoor activities decrease during hotter weather and do not shift to earlier times of the day as is commonly believed.
- Being a native of the Southwest or spending more time there did not lead to higher ecological knowledge.
- The number of years a respondent spent living in metropolitan Phoenix was negatively correlated for preference for the drier landscapes.

The central objective of the <u>Ecological and Social Interactions in Urban Parks</u> study is to use small, neighborhood parks in Phoenix to study: (1) the ways in which ecological processes are influenced by human values, use, and management; and (2) the ways in which human attitudes and activities, and the services valued by humans, are influenced by ecological characteristics and processes. Elucidating this coupling in Phoenix parks is itself a significant step towards understanding the complexities of human-nature interactions. The information gathered in addressing the central objective, though, can and should be used to assess potential trajectories for ecological processes. Our second objective is to develop trajectories for potential changes in ecosystem services in the Phoenix metropolitan area, given economic and demographic trends, and given the signal of human-nature interactions among different social groups. We have evaluated bird diversity (species richness and abundance) in 16 parks and neighborhoods. Species richness is highest in upper income neighborhoods and parks, intermediate in middle-income neighborhoods and parks, and lowest in low-income neighborhoods and parks (Kinzig *et al.* 2005, Warren *et al.* in review). Avian communities in low-income neighborhoods are largely nested subsets of those appearing in upper- and middle-income neighborhoods, with the disappearance of insectiverous species in the more depauperate communities and the idiosyncratic appearance of avian species associated with livestock.

We examined use in 16 parks in the morning and evening hours with on-site surveys in two different seasons (fall and spring). Overall, the number of people using the parks did not differ significantly by the income category of the surrounding neighborhood. On average, males (of all ages) were significantly more likely to use the park than females. We conducted a mail-out survey in 6 of our 16 neighborhoods, asking questions about landscaping preferences, neighborhood attachment, and park use. The main results are as follows:

- Park settings oriented towards recreation (open, built structures) are preferred over park settings dedicated to conservation (nature, garden).
- In contrast, all types of yards are equally popular, with the exception of a yard looking natural, which received the lowest support.
- Preferences for park and yard settings appear to be correlated–that is, if a respondent preferred a park with built structures, he/she also tended to prefer a yard with built structures.

The Biodiversity and Neighborhood Social Variation project will establish long-term monitoring of birds at a set of sites sites selected in a similar manner to the parks sites studied in CAP1, but will be co-located with Survey 200 and PASS sites. This will allow us to simultaneously monitor changes over time in the relationship between biodiversity and neighborhood social variation. Data collection has not yet begun on this project, but over the past year we have focused on selecting sites in collaboration with the PASS. We made progress toward selecting the new sites by analyzing the 2000 U.S. Census tract-level socio-demographic data for all 643 tracts in the Phoenix metropolitan area. Using factor analysis, each tract has been assigned to 1 of 11 neighborhood types (e.g., low income, predominately white or middle income, mixed ethnicity). The Survey 200 points have been mapped onto the tracts so that we can strategically select different types of neighborhoods into the sample. The data from the 2005 Survey 200 have been input for analysis and checking of those (primarily urban fringe) areas where land use and neighborhood type has changed in 5 y.

Informatics

The work on NSF-BDI (McCartney *et al.* 1999) funded projects 1) Ecological Metadata Language, 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 continues. All these products are implemented in SEINet (http://seinet.asu.edu). The search engine

Xanthoria has been deployed at several other institutions within Arizona and the LTER network. The metadata for over 100 datasets have been encoded in EML and are searchable and downloadable in SEINet and searchable through the Metacat server at LNO. Xanthoria and Xylopia currently are adapted for Grid use. Mapping and taxonomic applications for the collections databases have become important tools used extensively by the collections community in Arizona. The Ecology Explorers data analysis wizard is completed (http://caplter.asu.edu/eeAnalysis/) and together with other parts of the web site received the ASU President's award for Innovation. The wizard is based on the SEINet infrastructure and allows students to analyze data statistically and graphically. The next step is to include actual research data from CAP into this wizard which currently analyses data the students have collected in their school. Workflow scripts to integrate urban ecological models from government partners have been written in the Kepler framework 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 the workflow-processing system.

IV. Literature Cited

Baker, L. A., D. Hope, Y. Xu, J. Edmonds, and L. Lauver. 2001. Nitrogen balance for the Central Arizona-Phoenix ecosystem. *Ecosystems* 4:582-602.

Baker, L. A., T. Brazel, and P. Westerhoff. 2004. Environmental consequences of rapid urbanization in warm, arid lands: Case study of Phoenix, Arizona (USA). *In* N. Marchettini, C. Brebbia, E. Tiezzi, and L.C. Wadhwa, eds., *The Sustainable City III.* Advances in Architecture Series, WIT Press, Boston, MA.

Boreson, J., A. M. Dillner, and J. Peccia. 2004. Correlating bioaerosol load with PM2.5 and PM10cf concentrations: A comparison between natural desert and urban fringe aerosols", Atmospheric Environment 38: 6029-6041.

Burns, E. K., and E. D. Kenney. 2005. Building and maintaining urban water infrastructure: Phoenix, Arizona from 1950 to 2003. *Yearbook of the Association of Pacific Coast Geographers* 67:47-64.

Buyantuyev, A., C. Gries, and J. Wu. In review. Estimating vegetation abundance in urban environment based on Landsat ETM+ imagery: A case study in Phoenix. USA. *Remote Sensing of Environment*.

Celestian, S. B., and C. A. Martin. 2004. Rhizosphere, surface, and under tree canopy air temperature patterns at parking lots in Phoenix, AZ. *Journal of Arboriculture* 30:245-252.

Cook, W. M., D. G. Casagrande, D. Hope, P. M. Groffman and S. L. Collins. 2004. Learning to roll with the punches: Adaptive experimentation in human-dominated systems. Frontiers in Ecology and the Environment 2:467-474.

Cronon, W. 1995. Introduction: In search of nature. Pp. 23-56 *in* W. Cronon, ed. *Uncommon Ground: Rethinking the human place in nature*. W. W. Norton and Company, New York.

Dunlap, R., K.Van Liere, A. Mertig, and R. E. Jones. 2000. Measuring endorsement of the New Ecological Paradigm: A revised NEP scale. *Journal of Social Issues* 56(3):425-442.

Edmonds, J. W., N. B. Grimm, D. Hope, and L. A. Baker. In preparation. Long-term trends in streamwater chemistry above and below a desert city. *Water Resources Research*.

Faeth, S., and J. Sabo. 2005. *Trophic dynamics human-dominated environments.* Grant #0444228 from National Science Foundation, Directorate of Biological Sciences.

Faeth, S. H., P. S. Warren, E. Shochat and W.A. Marussich. 2005. Urban trophic dynamics. *BioScience* 55(5):399-407.

Fink, J., F. Steiner, N. B. Grimm, and C. L. Redman. 2003. Greater Phoenix 2100: Building a national urban environmental research agenda. Pp. 413-426 *in* G. Heiken, R. Fakundiny, and J. Sutter, eds. *Earth science in the city: A reader*. American Geophysical Union Monograph Special Publication Series Vol. #56.

Gober, P. A. In press. *Metropolitan Phoenix: Placemaking and community building in the desert.* University of Pennsylvania Press, Philadelphia.

Gober, P., C. Redman, R. Bolin, T. Taylor, J. Anderies, R. Balling, E. Corley, M. Crow, W. Griffin, A. Kinzig, M. Kuby, P. McCartney, M. Nelson, C. Saltz, W. Verdini, E. Wentz, D. White, J. Zehnder, R. Melnick, A. Razdan, and J. Rowe. 2003. *Decision Center for a Desert City: Science and policy of climate uncertainty.* Grant #0345945 from National Science Foundation, Directorate for Social, Behavioral/Economic Science.

Goettl, A. M., and N. B. Grimm. In revision. Seasonal and spatial variations in the limiting nutrient for an urban stream-lake system of central Arizona. *Freshwater Biology*.

Grimm, N. B., J. O. Allen, and S. J. Hall. 2005. *Collaborative research: Ecosystem response to N and organic C deposition from the urban atmosphere.* Grant #0514382 from National Science Foundation, Directorate for Biological Sciences.

Grimm, N. B., J R. Arrowsmith, C. Eisinger, J. Heffernan, D. B. Lewis, A. MacLeod, L. Prashad, W. J. Roach, T. Rychener, and R. W. Scheibley. 2004. Effects of urbanization on nutrient biogeochemistry of aridland streams. Pages 129-146 *in* R. DeFries, G. P. Asner, and R. Houghton, eds., *Ecosystem interactions with land use change*. American Geophysical Union.

Grimm, N. B., R. W. Sheibley, C. Crenshaw, C. N. Dahm, W. J. Roach, and L. Zeglin. 2005. Nutrient retention and transformation in urban streams. *Journal of the North American Benthological Society* 24:626-642.

Grossman-Clarke, S., Hope, D., Zehnder, J.A., Fernando, H.J.S. Stefanov, W.L., Hyde, P.G. 2005. NO_x-derived N dry deposition in the Phoenix metropolitan area: effects of urban vegetation. Submitted *Ecological Modeling*.

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://caplter.asu.edu/contributions).

Heisler, G. M., and Y. Wang. 2002. *Applications of a human thermal comfort model.* Fourth Symposium on the Urban Environment, American Meteorological Society, May 20-24, 2002, Norfolk, VA.

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

Hope, D., C. Gries, W. Zhu, W. F. Fagan, C. L. Redman, N. B. Grimm, A. L. Nelson, C. Martin, and A. Kinzig. 2003. Socioeconomics drive urban plant diversity. *Proceedings of the National Academy of Science* 100(15):8788-8792.
Online: http://www.pnas.org/cgi/doi/10.1073/pnas.1537557100.

Hope, D., C. Gries, Zhu, W., C. Martin, C. L. Redman, N. B. Grimm, A. Nelson, and A. Kinzig. In press *b*. Spatial variation in plant diversity and soil nitrate concentrations across an urban ecosystem. *Urban Ecosystems*.

Huete, A. R. 1988. A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment* 25:295-309.

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

Jenerette, G. D., J. Wu, N. B. Grimm, and D. Hope. In press *b*. Points, patches and regions: Scaling soil biogeochemical patterns in an urbanized arid ecosystem. *Global Change Biology.*

Jones, N., A. Brazel, C. Eisinger, S. Harlan, B. Hedquist, S. Grineski, D. Jenerette, L. Larsen, M. Lord, J. Parker, L. Prashad, N. Selover, W. L. Stefanov, and D. Zeigler. 2003. Neighborhood ecosystems: Human-vegetation-climate interactions in a desert metropolis. Poster presented at *CAP LTER Fifth Annual Poster Symposium,* February 19, 2003, Center for Environmental Studies, Arizona State University.

Joshi, H., S. Guhathakurta, G. Konjevod, Ke Li, and J. Crittenden. 2005. Simulating Impact of Light Rail on Urban Growth in Phoenix: An Application of UrbanSim Modeling Environment. Paper presented June 30, 2005, at the Computer Use in Urban Planning and Urban Management Conference, London: University College London (a version is also currently under review for journal publication).
http://caplter.asu.edu/Symposia/Symp2003/Jones_et_al.pdf

Kaye, J.P., P. M. Groffman, N.B. Grimm, and R. Pouyat. In review. A distinct urban biogeochemistry? *Trends in Ecology and Evolution*.

Li, Ke, Daniel Gerrity, Subhrajit Guhathakurta, John Crittenden, Anil Sawhney, Harindra Fernando, Peter McCartney, Nancy Grimm, Himanshu Joshi, Goran Konjevod, Jennie Si,Yu-jin Choi, Sonja Winter, Yongsheng Chen, Braden Allenby, "Informed Decision Making towards a More Sustainable Urban Development," International Society of Industrial Ecology Meeting, June 2005, Stockholm, Sweden.

Kinzig, A. P., P. S. Warren, C. Gries, D. Hope, and M. Katti. 2005. The effects of socioeconomic and cultural characteristics on urban patterns of biodiversity. *Ecology and Society*10:23. Online http://www.ecologyandsociety.org/vol10/iss1/art23/

Kinzig, A. P., J. Antle, W. Ascher, W. Brock, S. Carpenter, F. S. Chapin III, R. Costanza, K. Cottingham, M. Dove, H. Dowlatabadi, E. Elliot, K. Ewel, A. Fisher, P. Gober, N. Grimm, T. Groves, S. Hanna, G. Heal, K. Lee, S. Levin, J. Lubchenco, D. Ludwig, J. Martinez-Alier, W. Murdoch, R. Naylor, R. Norgaard, M. Oppenheimer, A. Pfaff, S. Pickett, S. Polasky, H. R. Pulliam, C. Redman, J. P. Rodriguez, T. Root, S. Schneider, R. Schuler, T. Scudder, K. Segersen, R. Shaw, D. Simpson, A. Small, D. Starrett, P. Taylor, S. Van der Leeuw, D. Wall, and M. Wilson. 2000. Nature and Society: An Imperative for Integrated Environmental Research. *in Report of a workshop to the National Science Foundation*, Tempe, AZ.

Kinzig, A. P., and C. Redman. 2002. *Spatial and temporal aspects of resilience in urban systems*. Grant #012768-001 from James S. McDonnell Foundation.

Kirby, A., S. L. Harlan, L. Larsen, E. J. Hackett, B. Bolin, D. Hope, A. Nelson, T. Rex, and S. Wolf. In press. Examining the significance of housing enclaves in the metropolitan United States. *Housing, Theory and Society*.

Larsen, L., S. Harlan, R. Bolin, E. Hackett, D. Hope, A. Kirby, A. Nelson, T. Rex, and S. Wolf. 2004. Bonding and bridging: Understanding the relationship between social capital and civic action. *Journal of Planning Education and Research* 24:64-77.

Larsen, L., and S. Harlan. In press. Desert dreamscapes: Preference and behavior. *Landscape and Urban Planning.*

Larson, E. K., and N. B. Grimm. In preparation. Redistribution of water across an urbanized desert basin: shifting hot spots of denitrification? *Ecosystems.*

Lewis, D. B., and N. B. Grimm. In preparation. Local features mediate regional drivers of nitrogen export from catchment ecosystems. *Water Resources Research.*

Lewis, D. B., Kaye, J. P., Gries, C., Kinzig, A. P., Redman, C. L., In review. Agrarian legacy in soil nutrient pools of urbanizing arid lands, *Global Change Biology*.

Likens, G. E. 1992. The ecosystem approach: Its use and abuse. *Excellence in Ecology, Vol. 3*. Ecology Institute, Oldendorf/Luhe, Germany.

Majumbar, A., J. P. Kaye, C. Gries, D. Hope, R. Burdick, and N. B. Grimm. In review. Hierarchical spatial modeling of multiple soil nutrients and carbon in heterogeneous land-use patches of the Phoenix metropolitan area. *Ecological Modeling.*

Martin, C. A., K. A. Peterson, and L. B. Stabler. 2003. Residential landscaping in Phoenix, Arizona: Practices, preferences and covenants codes and restrictions (CC&Rs). *Journal of Arboriculture* 29(1):9-17.

McCartney, P., N. B. Grimm, C. L. Redman, T. Craig, and C. Gries. 1999. *Networking our Research Legacy: Infrastructure to Document, Manage, and Access Ecological Data Resources. Biological Databases and Informatics* Award, National Science Foundation, DBI-9983132.

McCartney, P., P. Arzberger, C. Gries, R. Quay, and C. L. Redman. 2002. *Networking Urban Ecological Models through Distributed Services.* Biological Infrastructure ITR Small Grants Award, National Science Foundation, EIA-0219310.

Mueller, E. C., and T. A. Day. 2005. The effect of urban ground cover on microclimate, growth and leaf gas exchange of oleander in Phoenix, Arizona. International Journal of Biometeorology 49:244-255.

Mulholland, P., J. Webster, S. Hamilton, J. Tank, and R. O. Hall. (N. B. Grimm subcontract). 2001. Nitrate uptake and retention in streams: mechanisms and effects of human disturbance. Integrated Research Challenges in Environmental Biology Award, National Science Foundation, 2001-2006, DEB-0111410.

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.*

Prashad, L., W. L. Stefanov, A. Brazel, S. Harlan, and N. Jones. 2003. Decomposing a correlation between high temperature and low income at a neighborhood scale with thermal infrared imagery in Phoenix, Arizona. Poster presented at *LTER All Scientists Meeting,* September 19, 2003, Seattle, WA.

Redman, C. L., and A. P. Kinzig. 2003. Resilience of past landscapes: Resilience theory, society, and the long durée. *Conservation Ecology* 7(1):14.
Online: http://www.consecol.org/vol7/iss1/art14.

Redman, C. L., A. Kinzig, D. Foster, M. Gutmann, and P. Kareiva. 2002. Agrarian landscapes in transition: A cross-scale approach. Biocomplexity: Coupled Human-Natural Systems Award, National Science Foundation, BCE-0216560. (http://ces.asu.edu/agtrans).

Roach, W. J., R. Arrowsmith, C. Eisinger, N. B. Grimm, and J. Heffernan. In review. Anthropogenic changes in the hydrology and geomorphology of an urban desert stream: the implications for biogeochemical cycles. *Water Resources Research*.

Roach, W. J., and N. B. Grimm. In preparation. Denitrification in a stream-floodplain complex of a desert city: importance of natural and anthropogenic cross-system linkages. To be submitted to Ecological Applications.

Shen, W., J. Wu, J. F. Reynolds, and N. B. Grimm. In press. Simulating the dynamics of productivity of a Sonoran ecosystem: model parameterization and validation. Ecological Modeling.

Shochat, E. 2004. Credit or debit? Resource input changes population dynamics of city-slicker birds. Oikos 106:622-626.

Shochat E., S. Lerman, M. Katti, and D. Lewis. 2004. Linking optimal foraging behavior to bird community structure in an urban-desert landscape: Field experiments with artificial food patches. *American Naturalist*.

Stabler, L.B. and C. Martin. 2000. Irrigation regimens differentially affect growth and water use efficiency of two Southwest landscape plants. *Journal of Environmental Horticulture* 18:66-70.

Stabler, L.B. and C.A. Martin. 2004. Irrigation and pruning affect growth and water use efficiency of two desert-adapted shrubs. *Acta Horticulturae* 638:255-258.

Stabler, L.B., C. Martin and J. Stutz. 2001. Effect of urban expansion on arbuscular mycorrhizal mediation of landscape tree growth. Journal of Arboriculture 27:193-200.

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

Warren, P. S., C. A. Martin, and A. P. Kinzig. In press. Human socioeconomic factors and lifestyle factors predict avian community structure. *Ecological Applications.*

Wu, J., B. Jones, H. Li, and O. L. Loucks. In press. *Scaling and uncertainty analysis in ecology.* Columbia University Press, New York.

Wu, J. G., and J. L. David. 2002. A spatially explicit hierarchical approach to modeling complex ecological systems: theory and applications. *Ecological Modelling* 153:7-26.

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

V. Research Training and Development

CAP LTER's university setting enhances the ability to conduct, communicate, and synthesize our research activities. Faculty members have expanded their courses to consider urban ecology and, in some cases, have designed new courses to accommodate CAP LTER research interests. In addition, postdoctoral associates and graduate assistants gain exposure to interdisciplinary research, the importance of long-term datasets, metadata, and data archiving, as well as experience in database design and management, lab processing and analysis. The Goldwater Lab for Environmental Science accommodates CAP LTER's analytical needs and provides graduate-student training on instruments housed in its facility. Opportunities for summer support for graduate research and undergraduate research experiences are available. Theses and dissertations completed and in progress are listed below. Additional information is included in Contributions to Human Resource Development section below.

Theses and Dissertations

In Progress

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

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).

CAP-Sponsored Student Research

Robert Bills, School of Life Sciences: Growth effects on *Encelia farinose* (Brittlebush) Due to Suppression of Arbuscular Mycorrhizal Fungi at an Urban and a Desert Site

Catherine Singer: Effects of Organic and Inorganic Surface Mulches on Surface Energy Balance and Biotic Responses of Drip-Irrigated Xeric Landscapes

Brandon McLean, Geological Sciences: Water Chemistry at CAP LTER and Tempe Town Lake Sites to Understand Human Influence Patterns

Xiaoding Zhuo, Dept of Chemistry and Biochemistry: Patterns of Trace Element Distribution in an Urban-Desert System

Elisabeth Larson and Jason Walker, School of Life Sciences (additional awards sponsored by IGERT in Urban Ecology): Research on Ecosystem Services

VI. Education and Outreach

Education and outreach activities are woven throughout CAP LTER. We are committed to sharing what we learn with community organizations, governmental agencies, industry, and the general public. For example, in September 2004, a presentation on climate change and environmental justice was made to an interdisciplinary workshop of international humanities faculty and students, activists, and students from a community college and a high school in Nogales, Mexico. Simultaneous Spanish translation was provided and discussion centered on comparisons of drought and heat in Nogales and Phoenix.

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, which are in high demand. From the initial collaboration with 12 schools in 1998, Ecology Explorers has expanded to include over 100 teachers in 25 school districts, 4 charter schools and 2 private schools. Each year, 10-15 scientists including faculty members, research technicians, postdocs, graduate students, and advanced undergraduates participate in the internships, workshops, and classroom visits. We recruit science teachers (grades 5-10) from across the metropolitan Phoenix area and particularly encourage those teachers in underserved populations to participate. The program is aligned with the Arizona State Education Standards, including science, math, writing, social science and technology standards. This summer 14 new teachers participated in a two-week urban birds and plants internship that included developing birding point-count sites at the Desert Botanical Garden and at the Gilbert Riparian Preserve for use during school-year field trips. A hallmark of the Ecology Explorers program is continued teacher support during the academic year; we work with teachers in their classrooms as well as hold day-long workshops based on teacher requests. This year, we developed a new workshop on urban land use and conducted three day-long workshops for science teachers in the Gilbert Unified School District.

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 IIS 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, and in 2004, the Ecology Explorers' team received the ASU President's Award for Innovation. An advisory committee of informal education institutions, school districts, and ASU outreach programs meets yearly to advise our education team.

Service at the Salado is funded through the NSF Environmental Education Fund, an LTER supplement, Nina Mason Pulliam Charitable Trust. and the ASU University-School Partnership Faculty Initiative. Four schools established after-school science clubs that engage children in a local environmental project while performing a valuable community service. Seventy middle school children and eight ASU undergraduates participated in the Service Learning after-school clubs. Additional information can be found at http://caplter.asu.edu/explorers/riosalado.

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 takes this charge very seriously, sponsoring Greater Phoenix 2100 (GP2100) and, in April 2003, establishing the Consortium for the Study of Rapidly Urbanizing Regions (CSRUR). Following a large private donation in 2004, the Center for Environmental Studies was transformed into the International Institute for Sustainability (IIS), which is the home base of CAP LTER, as well as CSRUR, GP2100, the Decision Center for a Desert City, the Urban Ecology IGERT, and many other programs. The IIS's outreach efforts, primarily founded in knowledge generated by CAP LTER, engage academic, business, and governmental groups in dialogues about pressing environmental issues affecting our rapidly growing desert metropolis. The IIS produces a weekly e-newsletter digest with events, announcements, and job posting that are of interest to the university and community. CSRUR issues timely "Research Vignettes" 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 provides 3-D portrayals of scenarios for policy makers. To date, the EAtlas and a version in book form, the *Greater Phoenix Regional Atlas,* have been produced, and the Decision Theater opened in May 2005. CAP LTER models and data figure prominently in Decision Theater scenarios.

In addition to these use-inspired initiatives, Sustainable Materials and Renewable Technologies (SMART) program is working closely with private industry and state and local agencies to minimize the impacts of rapid urbanization, through existing and emerging technologies and sound policy recommendations. The Sustainability Partnership Enterprise, a quasi-consulting arm of the IIS, engages policy makers, resource managers, and industry leaders in planning and responding to the challenges of urban growth, environmental protection, resource management, and social and economic development. 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. IIS plays a central, liaison role in ensuring effective knowledge exchange from academic researchers (i.e., CAP LTER) to decision makers and end users of the science.

The highlight of each year is the CAP LTER Annual Poster Symposium, held in January or February. This day-long event, attended by researchers, students, K-12 teachers, community partners, and state and local agencies, features a keynote speaker and poster presentations by all supported projects (view posters at http://caplter.asu.edu/home/symposia.jsp). A midsummer workshop or retreat is held at an off-campus site in selected years to address theoretical issues (social science/natural science integration, contributions to ecological theory, and development of CAP2 were prior themes). Monthly All Scientist Meetings attract between 40 and 100 participants, including community partners, and feature scientific presentations by visitors or discussions of project results. CAP LTER news is presented on our web site and in the IIS newsletter.

Collaborations and Partnerships

ASU's membership in the Resilience Alliance (www.resalliance.org) has led us to explore what a "resilience" approach offers to CAP LTER and related research. This interdisciplinary group, whose primary focus is on contemporary systems, has expanded to examine whether archaeology and studies of the past can enhance understanding (e.g., Redman and Kinzig 2003). In addition, a continuing NSF Biocomplexity grant awarded in 2002 that examines agrarian transformations of landscapes in six areas of the US includes a resilience perspective (Redman *et al.* 2002).

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

Last summer (2004), 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 CSRUR. Redman is helping to 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. This year, Redman began serving as a member of the National Academies Steering Committee on Urban Sustainability in Secondary Cities of the Developing World, in association with a Gordon Moore grant to develop a pilot project on urban sustainability.

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

Maricopa Association of Governments (MAG), consisting of the 24 incorporated cites and towns, two Indian communities, and Maricopa County, has been an integral partner, supporting the project by supplying GIS information and data and collaborating on investigations into growth planning, land-use projections, and open-space implementation. We have also worked with the *Flood Control District of Maricopa County* in projects involving storm hydrology and storm-water chemistry.

Salt River Project, a semipublic organization responsible for water management and supplying electrical energy to the region, has a long-term research and outreach relationship with CAP LTER. They have greatly facilitated the work of the land-use team and have contributed greatly to the nitrogen mass balance study and even provided a helicopter to reach several remote Survey 200 sample locations. The *Desert Botanical Garden* serves as one of our long-term sampling sites. Lastly, over 30 businesses/organizations/federal, state, regional, and local agencies entertain long-term monitoring of ecological variables on their sites. A list of our community partners is included in the participants section.

In addition, CAP LTER participants partner with a wide range of institutions on associated projects. For example, our research teams have substantial collaborations, through workshops and publications, with scientists at the BES site, Coweeta, Shortgrasse Steppe, Kellogg, Konza Prairie, Jornada, Sevilleta, University of Michigan, The Nature Conservancy, Stanford University, University of Nevada Las Vegas, UNAM Hermosillo, University of Arizona, University of Melbourne's Center for Urban Ecology, numerous academic and research institutions through Grimm's involvement in the LINX project, and several institutions in China (e.g., East China Normal University, Beijing Normal University, Nanjing University, Inner Mongolia University, Institute of Botany of Chinese Academy of Sciences).

In addition, Ecology Explorers partners with the Desert Botanical Garden, the Gilbert Riparian Preserve, the Gilbert Unified School District, the Roosevelt School District, and Southwest Center for Education and the Natural Environment.

Dissemination of Research Projects and Results

This year CAP2 participants have produced 59 journal articles (24 published, 16 in press, 19 in review) and 15 books and book chapters (3 published, 11 in press, 1 in review). In addition research results are routinely presented at meetings and conferences in a diverse array of fields. During 2004- 2005, 45 presentations and posters were given at regional, national and international conferences, and 105 at LTER-related conferences.

We publish a newsletter 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 scientific journals such as *Science* and we continue to receive occasional press attention. Grimm was interviewed for a *Science Friday* (National Public Radio) program on urban ecology.

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

VII. Contributions

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.

Contributions within Discipline

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

- The 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. Current environmental literature indicates severe problems relating environmental behavior, values and knowledge. This research has already shown how environmental values are important, but we also show a specific mechanism by which environmental values become secondary to identity-based culturally and socially constructed norms and behaviors, such as notions of 'family'. A more detailed understanding of socio-ecological dynamics will emerge subsequent to experimental treatment. This project is unique in that we are studying the values, knowledge, social networks and behavior together.
- The NDV project has two major innovations: 1) The novel design in which humans (resident rental tenants) are incorporated as an integral part of the experimental design, and 2) the use of the adaptive experimental approach described above. More specific contributions include the installation of micrometerological stations within each of the landscape treatment areas to help understand the extent of under canopy microclimate variation related to variation in vegetation density.
- PASS contributes to the fields of urban sociology, environmental sociology, urban ecology, and planning and design. PASS provides unique human data on environmental values, behaviors, and preferences that have consequences for the natural and built environments.
- Current environmental literature indicates severe problems relating environmental behavior, values and knowledge. This research has already shown how environmental values are important, but we also show a specific mechanism by which environmental values become secondary to identity-based culturally and socially constructed norms and behaviors, such as notions of 'family'. A more detailed understanding of socio-ecological dynamics will emerge subsequent to experimental treatment. This project is unique in that we are studying the values, knowledge, social networks and behavior together.
- Aquatic Core Monitoring. For the Phoenix metropolitan area, the dams upstream of the city altered the flux and concentrations of dissolved constituents by reducing downstream discharge variability, low flow discharge, and the variability of several chemical constituents. While work elsewhere has found similar hydrologic effects in other ecosystems, the importance of these changes to water chemistry in a downstream metropolitan area has not been extensively discussed previously in the literature. Hence this work shows that biogeochemists studying urban stream and river systems may need to increase their spatial and temporal scales of study to better understand the feedbacks between human decision making and carbon and nutrient cycling
- Survey 200 findings provide a probability-based, spatially extensive snapshot of a suite of key ecological variables that is unique in covering the complex landscape of a rapidly

urbanizing region and surrounding desert. This data provides a framework for understanding the andlsquobig spatial picture across the CAP region and has been used extensively by a wide variety of project researchers (both faculty and students) over the last 12 months. As the initial primary data papers are now being published, we anticipate the data will become increasingly known to and used by the wider ecological research community.

- Neighborhood Ecosystem Study has made contribution to sociology, remote sensing/environmental science and planning. Sociology: Theoretical developments in urban sociology and urban ecology have provided new conceptual models for understanding organization and change in human-dominated ecosystems. Yet the adoption of integrative approaches to empirical research on urban environments is still relatively uncommon in the field of sociology. Many social science studies of cities and communities focus on income, status, and lifestyle, while ignoring altogether the material environment andndash people s interactions with physical places, modifications of biophysical properties, risks associated with environmental quality, and symbolic meanings they attribute to the environment. This study shows that human settlement changes the environment in ways that create inequalities of natural capital for marginal population groups, which in turn expose them to greater risks in health and well-being. Remote Sensing/Environmental Science: This study integrated three different datasets (MASTER, ASTER, and ETM+) to investigate the spatial and temporal variance in surface temperature and vegetation density across eight neighborhoods of varying socioeconomic status. Analysis of these data provided a common quantitative bridge between social and physical science methodologies and datasets. The results of the integrated analysis have improved our understanding of urban climate processes and provided a baseline for models of regional to neighborhood-scale climate and personal comfort levels. This information is of great interest to urban planners, air quality officials, climate and ecological researchers, utility service providers, and those exploring means to mitigate the effects of urban heat islands. The study also demonstrated the usefulness of MASTER, ASTER, and ETM+ thermal data for urban climate studies. Surface temperature data linked to land cover types is particularly useful for improvement of climate and surface process (i.e., weathering) models in urban environments. Planning: Urban planning extends beyond regulating land use to consider issues of equity, community participation, and environmental justice. Urban settlement patterns within the metropolitan regions of the United States represent the overt legacies of discrimination and segregation and the covert desires for exclusion, separation, and conformity. While planning attempts to understand and alter detrimental social patterns at the macro-level, less attention has been paid to the ecological implications of different urban settlement patterns. Our finding that the heat island most severely impacts the city s poorest residents has implications for allocating city funds and regulating new development. This work has also investigated individual decisions about where to settle, collective public action, and what constitutes a desirable physical neighborhood and social community. Some of our most interesting findings represent how individual residential decisions involve a series of complex trade-offs that involve little-understood preferences, market offerings, and investment opportunities. Identifying these trade-offs will help us to understand what desires motivate urban sprawl and what initiatives might discourage it.
- Arbuscular mycorrhizal (AM) fungi are obligate symbionts of approximately 75% of vascular plants in the world. AM fungi have been shown to impact plant productivity and stress tolerance, but little is known about their diversity in arid urban areas. Our

preliminary results indicatethat AM fungal species richness is decreased in urban areas compared to the surrounding deserts. This decrease may negatively impact net primary productivity in urban areas. We are currently investigated whether this decrease in species richness is associated with both native and exotic plants in urban areas or with just exotic plants.

- The information on mycorrhizal functioning and its impact on plant productivity in urban desert areas is limited. We have found that the effects of AM fungal inoculation on plant growth is dependent on the AM fungal and plant species and the abiotic conditions that the plant is growing under. Stabler et al (2001) found that there was less root colonization in the residential sites in comparison to trees growing in an adjacent urban park. What is currently unknown is the impact of AM fungi on net primary productivity in urban areas. This study uses the fungicide, benomyl to suppress mycorrhizal colonization allowing a comparison between plants with normal colonization and those with low levels of colonization. The results of this project should allow us to compare the impact of AM fungi on plant productivity of the same plant species (brittlebush) when it is growing in a arid urban areas and in the surrounding desert.
- The riparian restoration project furthers understanding of riparian community structure and function along urban arid region rivers, which is a little studied subject within the field of ecology. More specifically, this project addresses the importance of horizontal and lateral connectivity to riparian community species richness within a river corridor, and also highlights the functional role of constructed stormdrains as urban tributaries. In addition, most of the study sites lie within portions of the river slated for restoration. Therefore this investigation could provide baseline information to restoration managers and project planners. Some significant findings of particular importance to restoration success include the identification of several plant species that were previously uncollected or rarely collected along the Salt River, as well as the low soil seed bank richness compared to reference rivers.

Contributions to Other Disciplines

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

Subsequent data analysis will focus on how social variables we re studying effect behavior, which ultimately affects biophysical landscape processes.

- Findings from the NDV experiment could potentially be of interest in fields such as architecture and landscape planning, as the interactions between people and specific landscape types become apparent. Other products could be an improved understanding of the effect of different landscaping types on power and water useage - both from the biophysical effects of the landscapes themselves, and on the behaviours of residents within different experimental landscapes. For example - will people living in xeric (low water use, desert-like) treatments become more aware of water conservation issues and lower their in-home water use? Subsequent data analysis will focus on how social variables we are studying affect behavior, which ultimately affects biophysical landscape processes
- Survey 200 data have been used to develop and improve methodologies in the fields of remote sensing, urban atmospheric science and spatial statistics, with publications/ submissions to peer-reviewed journals in all these fields.
- We believe the Neighborhood Ecosystem Study advanced interdisciplinary science by demonstrating that people trained in a wide array of disciplines can agree on important research questions and collaborate on investigating complex scientific problems that require a range of knowledge and skills. We resolved issues of scale and measurement, defined key indicators, and related social and ecological variables to each other on two different spatial scales.

Contributions to Resources for Research and Education

- LTER's setting within a university enhances the ability to conduct, communicate, andsynthesize research activities. Faculty members have expanded their courses to include a consideration of urban ecology and, in some cases, have designed new courses toaccommodate 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. Inaddition, 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 International Institute for Sustainability, the administrative home for the CAP LTER, houses the Informatics Lab, provides support and management staff, and shared office space and meeting facilities for CAP participants. This infrastructure supports services that enhance the dissemination of project results, foster new collaborations, enable access to project data resources, engage K-12 students in the science of the CAP LTER, and reach out to community members and organizations. Interdisciplinary working groups are organized, that often result in the generation of new research opportunities and funding.
- The Southwest Environmental Information Network (SEINet) was created to serve as a gateway to distributed data resources of interest to the environmental research community in Arizona and beyond. Through a common web interface, we offer tools to locate, access, and work with a variety of data including biological collections, ecological research data, GIS data, taxonomic name information, bibliographies, and research protocols. Data collected as part of the Geological Remote-Sensing Lab's research programs is archived 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.

- The Goldwater Lab for Environmental Science has been expanded to accommodate the project's analytical needs and provide graduate-student training on instruments housed in this facility.
- Collaborations such as Ecology Explorers and Service at the Salado share project results with underserved community schools to enrich programming and encourage future educational pursuits in the sciences.

Contributions to Human Resource Development

The CAP LTER provides a powerful framework for training graduate students, nourishing 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.

- Since the inception of CAP LTER, 26 postdoctoral associates have taken leadership roles in research and outreach activities. The project currently supports five postdocs, three 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 annual poster symposium and summer summit. They are integral to the research and field experience of CAP LTER and receive training in interdisciplinary collaboration, graduate-student supervision, data collection and analysis, and presentation techniques.
- Six graduate students a semester are involved in CAP2, each immersed in the research at hand and working together as a cohort for the project at large. They are drawn from a wide range of university programs, departments, and schools, representing disciplines such as anthropology, biology, curriculum and instruction, engineering, economics, geography, geological sciences, planning and landscape architecture, plant biology, and sociology. Graduate students serve as research associates and are trained in field-investigation techniques, data analysis, scientific writing, oral presentation, interdisciplinary interaction, GIS, and remote sensing. In 2004 CAP established a competitive summer graduate student grant program under which four grants have been awarded. Faculty members in geography, geological sciences, life sciences, and civil and environmental engineering have delivered additional training through graduate courses designed around CAP LTER activities.
- CAP LTER faculty members, postdoctoral associates, and senior graduate students have mentored 26 NSF-funded REU students who gained research training via summer projects integral to CAP LTER. Undergraduates from ASU who are working on CAP can be part of the the new Community of Undergraduate Scholars and the Community of Undergraduate Interns, a new program sponsored by the International Institute for Sustainability and the Barrett Honors College. Other undergraduate students have benefited by participating in data collection for the ground arthropod and bird studies, parks-use surveys, collection and curation activities, and courses that relate to the CAP LTER. Project research has also been incorporated into undergraduate honors and senior theses.
- Monthly All Scientists 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. Smaller groups of CAP researchers assemble for various projects. Remote Sensing Working Group meetings have been held to foster collaborations among CAP LTER scientists doing research involving remote sensing via discussion of ongoing and planned work, proposal generation, image acquisition, and workshops. Other working groups, such as atmospheric deposition, human feedbacks, soils, and modeling, meet as needed. A new working group on ecosystem services for CAP has just begun, and the PASS project uses a working group format to plan its study design.

- The Schoolyard LTER supplement has created special opportunities for K-12 teachers to work alongside LTER researchers in summer internships on several monitoring projects. CAP graduate students and postdocs 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 International Institute for Sustainability. CAP participants serve as judges each year in the Central Arizona Science and Engineering Fair and the American Indian Science and Engineering Fair.

Contributions Beyond Science and Engineering

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

- 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.
- Droughts and water shortages, combined with explosive growth of urban and suburban areas, have created a situation that is being viewed with increasing concern across the western United States. Community participation inherent to this project, integration with public policy, and publication of research results will greatly facilitate our ability to address water-related environmental problems in the Southwest.
- The Phoenix Area Social Survey (PASS) promises to contribute to the solution of social problems, providing information for planning urban growth, especially in sensitive ecosystems. The interdisciplinary team of researchers from sociology, planning, geography, geology, biology, and economics contributes to the burgeoning fields of urban sociology, urban ecology, and environmental sociology. PASS provides unique data on human values, behaviors and preferences that have consequences for the natural and built environments and is a data resource for several on-going CAP LTER projects, including neighborhood ecosystems, environmental risk, and urban parks. PASS could be expanded to provide long-term monitoring of social conditions in the metropolitan area comparable to on-going monitoring of ecological conditions. The inclusion of neighborhoods sited at Survey 200 locations will allow integrative analyses of social and ecological conditions.

- Communities, social lives, values, and behaviors must be understood in order to comprehend the place of humans in the environment. This is vitally important in rapidly urbanizing regions, such as Phoenix. Arid cities face unique environmental challenges that accompany population growth, including extreme heat, limited water resources and shade, and harsh conditions for species survival. Many scientists and policy makers believe that these challenges can be overcome only creating strong, engaged communities that understand and appreciate their biophysical environments. The PASS is a vehicle for increasing our knowledge of how residents shape and resp ond to the local environment, which is a necessary step in devising a more sustainable city.
- The aquatic core monitoring work has two main implications: 1) It suggests that decisions regarding groundwater usage will feedback on chemistry patterns of water leaving the city. Therefore, a significant reduction in nutrients and salt concentrations should result as Phoenix begins to reduce agricultural activity and increase residential development in its place. 2) The presence of dams upstream of the city dampened the variability and stochastic nature of water chemistry in the two rivers entering the city. For example, the Salt and Verde rivers are the primary sources of drinking water for the city. Therefore, the increase in C and N loads, as well as the amelioration of salt loading, could have important consequences for the water treatment process.
- The Salt River riparian seed bank and Hassayampa channel stability projects each address fundamental knowledge at specific sites that is needed for effective flood management or river restoration. Because study sites lie within portions of the rivers slated for restoration or development, this project will provide baseline information to restoration managers and project planners.
- Survey 200 data provide regional planners and public policy makers a unique information source for how explosive urban and suburban growth is changing the ecological resources of the CAP region. As data analysis and modeling efforts continue to be refined, they will provide the facility to predict how future urban growth will affect the ecological infrastructure in the region.
- Neighborhood Ecosystems Study: International and government agencies are seeking to reduce illness, mortality, and the other human costs of climate change. Significant climate change attributable to urbanization, however, has been measured in the Phoenix, AZ area during the last 100 years and it is projected to continue along with urban growth. The neglect of poor inner-city neighborhoods and construction of new large-scale middle class housing developments on the desert fringe intensify and enlarge the urban heat island through the replacement of vegetation with impervious surfaces and heavy traffic. The inequalities in biophysical environments between more affluent, predominately white neighborhoods and the lower- to middle-income neighborhoods continue to put economically and socially marginal populations at a higher risk of exposure to excessive heat and all that it entails. Social, ecological, and climate changes are likely to continue in the future in some of the world s fastest-growing metropolises that, like Phoenix, are located in arid and semi-arid regions. Arid cities face unique environmental challenges that accompany population growth, including extreme heat, limited water resources and shade, and harsh conditions for species survival. Just as the causes of climate change are complex, finding solutions is also challenging because the resources necessary for mitigating heat—land, water, and energy—are environmentally scarce. This study used multidisciplinary data and methods to understand some of the social and ecological factors that cause urban climate change and the equity issues that arise from dealing with its causes and effects. Hopefully with an increased understanding of what produces

microclimate variation on a small scale, designers, engineers, and health professionals will work towards building sustainable cities for all inhabitants and target heat mitigation strategies to the most vulnerable people.

VIII. Publications 2004-2005

Journal Articles

In Press

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

Hope, D., C. Gries, D. Casagrande, C. L. Redman, N. B. Grimm, and C. Martin. In press. 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 press. Spatial variation in soil inorganic nitrogen across an arid urban ecosystem. *Urban Ecosystems*.

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

Jenerette, G. D., J. Wu, N. B. Grimm, and D. Hope. In press. Points, patches and regions: Scaling soil biogeochemical patterns in an urbanized arid ecosystem. *Landscape Ecology.*

Kirby, A., S. L. Harlan, L. Larsen, E. J. Hackett, B. Bolin, D. Hope, A. Nelson, T. Rex, and S. Wolf. In press. Examining the significance of housing enclaves in the metropolitan United States. *Housing, Theory and Society*.

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

Lewis D. B., J. D. Schade, A. K. Huth, and N. B. Grimm. In press. The spatial structure of variability in a semi-arid, fluvial ecosystem.*Ecosystems* .

Musacchio, L. R., J. Ewan, and R. Yabes. In press. Regional landscape systems protection in the urbanizing desert Southwest: Lessons from the Phoenix metropolitan region. *Landscape Review.*

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

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

Stefanov, W.L., and M. Netzband. In press. Assessment of ASTER land cover and MODIS NDVI data at multiple scales for ecological characterization of an arid urban center. *Remote Sensing of Environment, ASTER Special Issue.*

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

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

Wentz, E. A., W.L. Stefanov, C. Gries, and D. Hope. In press. Land use and land cover mapping from diverse data sources for an arid urban environments. *Computers, Environment and Urban Systems*, In Press, Corrected Proof, Available online 23 May 2005.

(http://www.sciencedirect.com/science/article/B6V9K-4DTJP46-4/2/fff6ef4d6be0d665d14f5bd077078b73)
Zhu, W., D. Hope, C. Gries, and N. B. Grimm. In press. Soil characteristics and the accumulation of inorganic nitrogen in an arid urban ecosystem. *Ecosystems*.

In Review

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*.
Buyantuyev, A., C. Gries, and J. Wu. In review. Estimating vegetation abundance in urban environment based on Landsat ETM+ imagery: A case study in Phoenix. USA. *Remote Sensing of Environment.*
Casagrande, D. G., D. Hope, E. Farley-Metzger, W. Cook, and S. Yabiku. In review. Problem and opportunity: Integrating anthropology, ecology, and policy through adaptive experimentation in the urban American Southwest. Invited for special issue: *Human Organization*.
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. NOx-derived N dry deposition in the Phoenix metropolitan area: Effects of urban vegetation. *Ecological Modeling*.
Hall, S. J., N. B. Grimm, S. L. Collins, and J. D. Schade. In review. Soil nitrogen oxide fluxes in an urban ecosystem. *Ecosystems*.
Hope, D., C. Gries, P. Warren, M. Katti, G. Stuart, J. Oleson, and J. Kaye. In review. How do humans restructure the biodiversity of the Sonoran Desert? *Journal of the Rocky Mountain Research Station.*
Jenerette, G. D., S. L. Harlan, A. Brazel, N. Jones, L. Larsen, W. Stefanov. In review. The inequitable distribution of the heat island in an arid city. *Proceedings of the National Academy of Sciences of the United States of America.*
Kaye, J. P., P. M. Groffman, N. B. Grimm, and R. Pouyat. In review. A distinct urban biogeochemistry? *Trends in Ecology and Evolution.*
Lewis, D. B., J. P. Kaye, C. Gries, A. P. Kinzig, and C. L. Redman. In review. Agrarian legacy in soil nutrient pools of urbanizing arid lands. *Global Change Biology.*
Majumbar, A., J. P. Kaye, C. Gries, D. Hope, R. Burdick, and N. B. Grimm. In review. Hierarchical spatial modeling of multiple soil nutrients and carbon in heterogeneous land-use patches of the Phoenix metropolitan area. *Ecological Modeling.*
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.*
Roach, W. J., R. Arrowsmith, C. Eisinger, N. B. Grimm, J. B. Heffernan, and T. Rychener. In review. Anthropogenic modifications influence the interactions between the geomorphology and biogeochemistry of an urban desert stream. *Ecosystems.*
Shochat, E., P. S. Warren, S. H. Faeth, N. E. McIntyre, and D. Hope. In review. Urban evolutionary ecology: From pattern to emerging processes. *Trends in Ecology and Evolution*.
Walker, J. S., R. C. Balling, J. M. Briggs, M. Katti, P. Warren and E. M. Wentz. In review. Birds of a feather: A story of urban and exurban population biology. *Landscape Ecology.*
Walker, J. S., and J. M. Briggs. In review. An object-oriented approach to urban forest mapping with high-resolution, true-color aerial photography. *Photogrammetric Engineering and Remote Sensing.*

Warren, P. S., C. A. Martin, and A. P. Kinzig. In review. Human socioeconomic factors and lifestyle factors predict avian community structure in urban parks. *Ecological Applications.*

Whitcomb, S. A., and J. C. Stutz. In review. Assessing diversity of arbuscular mycorrhizal fungi in a local community: role of sampling effort and spatial heterogeneity. *Mycological Research.*

Wu, J., L. Zhang, and G. D. Jenerette. In review. Quantifying the spatiotemporal patterns of urbanization: A case study in metropolitan Phoenix, USA. *Landscape and Urban Planning*.

2005

Allenby, B., and J. H. Fink. 2005. Toward inherently secure and resilient societies. *Science* 309:1034-1036.

Brazel, A. J., H .J. S. Fernando, J. C. R. Hunt, N. Selover, B. C. Hedquist, and E. Pardyjak. 2005. Evening transition observations in Phoenix, Arizona, U.S.A. *Journal of Applied Meteorology* 44:99-112.

Burns, E. K., and E. D. Kenney. 2005. Building and maintaining urban water infrastructure: Phoenix, Arizona from 1950 to 2003. *Yearbook of the Association of Pacific Coast Geographers* 67:47-64.

Celestian, S. B. and C. A. Martin. 2005. Effects of parking lot location on size and physiology of four Southwest landscape trees. *Journal of Arboriculture* 31(4):191-197.

Douglass, J., R. I. Dorn, and B. Gootee. 2005. A large landslide on the urban fringe of metropolitan Phoenix, Arizona. *Geomorphology* 65(2005):321-336.

Faeth, S. H., P. S. Warren, E. Shochat, and W. Marussich. 2005. Trophic dynamics in urban communities. *BioScience* 55(5):399-407.

Grimm, N. B., R.W. Sheibley, C. Crenshaw, C. N. Dahm, W. J. Roach, and L. Zeglin. 2005. Nutrient retention and transformation in urban streams. *Journal of the North American Benthological Society* 24:626-642.

Kinzig, A. P., P. S. Warren, C. Gries, D. Hope, and M. Katti. 2005. The effects of socioeconomic and cultural characteristics on urban patterns of biodiversity. *Ecology and Society* 10(1):23. Online: http://www.ecologyandsociety.org/vol10/iss1/art23/

Mueller, E. C., and T. A. Day. 2005. The effect of urban ground cover on microclimate, growth and leaf gas exchange of oleander in Phoenix, Arizona. *International Journal of Biometeorology* 49:244-255.

Musacchio, L., E. Ozdenerol, M. Bryant, and T. Evans. 2005. Changing landscapes, changing disciplines: Seeking to understand interdisciplinarity in landscape ecological change research. *Landscape and Urban Planning* 73(2005):326–338.

Stabler, L. B., C.A. Martin, and A. J. Brazel. 2005. Microclimates in a desert city were related to land use and vegetation index. *Urban Forestry & Urban Greening* 3:137-147.

2004

Berling-Wolff, S. and J. Wu. 2004. Modeling urban landscape dynamics: A case study in Phoenix, USA. *Urban Ecosystems* 7:215-240.

Boreson, J., A. M. Dillner, and J. Peccia. 2004. Correlating bioaerosol load with PM2.5 and PM10cf concentrations: A comparison between natural desert and urban fringe aerosols. *Atmospheric Environment* 38(35):6029-6041.

Cook, W. M., D. G. Casagrande, D. Hope, P. M. Groffman, and S. L. Collins. 2004. Learning to roll with the punches: Adaptive experimentation in human-dominated systems. *Frontiers in Ecology and the Environment* 2(9):467-474.

Grimm, N. B., and C. L. Redman. 2004. Approaches to the study of urban ecosystems: The case of central Arizona - Phoenix. *Urban Ecosystems* 7:199-213.

Jenerette, G. D., and J. Wu. 2004. Interactions of ecosystem processes with spatial heterogeneity in the puzzle of nitrogen limitation. *Oikos* 107(2):273-282.
Larsen, L., S. Harlan, R. Bolin, E. Hackett, D. Hope, A. Kirby, A. Nelson, T. Rex, and S. Wolf. 2004. Bonding and bridging: Understanding the relationship between social capital and civic action. *Journal of Planning Education and Research* 24:64-77.
Martin, C. A., and L. B. Stabler. 2004. Urban horticultural ecology: Interactions between plants, people and the physical environment. *Acta Horticulturae* 639:97-101.
Martin, C. A., and J. C. Stutz. 2004. Interactive effects of temperature and arbuscular mycorrhizal fungi on growth, P uptake and root respiration of *Capsicum annuum* L. *Mycorrhiza* 14(4):241-244.
Martin, C. A., P. S. Warren, and A. P. Kinzig. 2004. 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* 69(4):355-368. Available online: http://www.sciencedirect.com/science/article/B6V91-4B7D8N0-1/2/b1086f9449042f1ac6f02e83b80b2888
Musacchio, L., and J. Wu. 2004. Collaborative landscape-scale ecological research: Emerging Trends in urban and regional ecology. Special Issue of *Urban Ecosystems* 7:175-178.
Quay, R. 2004. Bridging the gap between ecological research and land use policy: The North Sonoran collaboration. *Urban Ecosystems* 7:283-294.
Wu, J. 2004. Key research topics in landscape ecology. *Acta Ecologica Sinica* 24(9):2074-2076.
Zhu, W.-X., N. D. Dillard, and N. B. Grimm. 2004. Urban nitrogen biogeochemistry: Status and processes in green retention basins. *Biogeochemistry* 71:177-196.

Books, Book Chapters, and Conference Proceedings

In Press

Harris, G., S. W. Bigelow, J. J. Cole, H. Cyr, L. L. Janus, A. P. Kinzig, J. F. Kitchell, G. E. Likens, K. H. Reckhow, D. Scavia, D. Soto, L. M. Talbot, and P. H. Templer. In press. The role of models in ecosystem management. In *Understanding ecosystems: The role of quantitative models in observation, synthesis, and prediction*. Princeton University Press.
Kinzig, A.P. In press. On the benefits and limitations of prediction. In press. In *Understanding ecosystems: The role of quantitative models in observation, synthesis, and prediction*. Princeton University Press.
Li, H., and J. Wu. In press. Uncertainty analysis in ecological studies: An overview. *In* J. Wu., H. Li, and O. Loucks, eds., *Scaling and uncertainty analysis in ecology.* Columbia University Press, New York.
Stefanov, W. L., and A. J. Brazel. In press. Challenges in characterizing and mitigating urban heat islands - a role for integrated approaches including remote sensing. *In* M. Netzband, W. L. Stefanov, and C. L. Redman, eds., *Applied remote sensing for urban planning, governance and sustainability.* Springer-Verlag.
Stefanov, W.L., and M. Netzband. In press. Characterization and monitoring of urban/peri-urban ecological function and landscape structure using satellite data. *In* Jürgens, C., and Rashed, T. (eds.), *Remote sensing of urban and suburban areas,* Kluwer Academic Publishers.
Walker, B., M. Anderies, G. Peterson, A. Kinzig, and S. Carpenter. In press. Robustness in ecosystems. In *A repertoire of robustness*. A Santa Fe Institute Lecture Note Series, Oxford University Press.
Wu, J., B. Jones, H. Li, and O. L. Loucks. In press. *Scaling and uncertainty analysis in ecology*. Columbia University Press, New York.
Wu, J., and H. Li. In press. Concepts of scale and scaling. *In* J. Wu., H. Li, and O. Loucks, eds., *Scaling and uncertainty analysis in ecology.* Columbia University Press, New York.

Wu, J., and H. Li. In press. Theories and methods in scaling: A review. *In* J. Wu., H. Li, and O. Loucks, eds., *Scaling and uncertainty analysis in ecology.* Columbia University Press, New York.

Wu, J. and H. Li. In press. Concepts and methods of scaling: A review. *In* J. Wu, B. Jones, J. Li, and O. L. Loucks, eds., *Scaling and uncertainty analysis in ecology*. Columbia University Press, New York.

Wu, J., H. Li, B. Jones, and O. Loucks. In press. Scaling with known uncertainty: A synthesis. *In* J. Wu, B. Jones, H. Li and O.L. Loucks, eds., *Scaling and uncertainty analysis in ecology*. Columbia University Press, New York.

In Review

McIntyre, N. E., and J. J. Rango. In review. Arthropods in urban ecosystems: Community patterns as functions of anthropogenic land use. *In* M. McDonnell, A. Hahs, and J. Breuste, eds., *Comparative ecology of cities and towns*. Cambridge University Press.

2004

Baker, L. A., T. Brazel, and P. Westerhoff. 2004. Environmental consequences of rapid urbanization in warm, arid lands: Case study of Phoenix, Arizona (USA). *In* N. Marchettini, C. Brebbia, E. Tiezzi, and L.C. Wadhwa, eds., *The Sustainable City III.* Advances in Architecture Series*,* WIT Press, Boston, MA.

Grimm, N. B., R. J Arrowsmith, C. Eisinger, J. Heffernan, D. B. Lewis, A. MacLeod, L. Prashad, T. Reichner, W. J. Roach, and R. W. Sheibley. 2004. Effects of urbanization on nutrient biogeochemistry of aridland streams. Pp. 129-146 *in* R. DeFries, G. Asner, and R. Houghton, eds., *Ecosystem interactions with land use change*. Geophysical Monograph Series 153, American Geophysical Union, Washington, DC.

Grossman-Clarke, S., J. A. Zehnder, and W. L. Stefanov. 2004. Urban modifications in a mesoscale meteorological model and the effects on surface energetics in an arid metropolitan region. In Preprint volume of 22-27 August 2004 *5th Symposium on the Urban Environment*, American Meteorological Society, Vancouver, BC, Canada.