CAP LTER PHASE 2: FINAL REPORT

I. OVERVIEW OF RESULTS, IMPACTS AND TRANSFORMATIVE RESEARCH

Overview

Phase 2 of the Central Arizona–Phoenix (CAP) Long-Term Ecological Research project featured a new conceptual framework, reorganized teams, research advances in multiple areas, and continued leveraging of funding and communication of results. As one of two urban sites funded in the US LTER network, CAP is advancing knowledge and theory in urban ecology (Grimm and Redman 2004; Grimm et al. 2008a; Wu 2008a, b) and, with other scientists globally, expanding the horizons of research on socioecological systems (SES; Redman et al. 2004; Haberl et al. 2006; Costanza et al. 2007; J. Liu et al. 2007a, b; Grimm et al. 2008b).

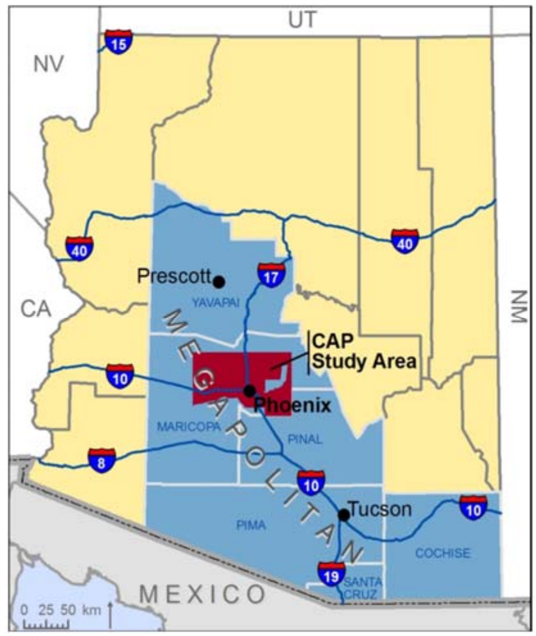

Figure 1. Map of Arizona, USA, showing extent of the Sun Corridor Megapolitan (blue shading) and the CAP study area within it (red shading). Gray lines are county boundaries.

The 6,400-km^2 CAP study area in central Arizona incorporates metropolitan Phoenix, surrounding Sonoran Desert scrub, and rapidly disappearing agricultural fields (Fig. 1). Rapid urbanization has been the dominant land change since the 1950s, accompanied by an order-of-magnitude increase in population. Coincident with rapid population growth, the rise of automobile transportation has led to air pollution and other problems that influence quality of life. Freshwater resources have been appropriated to support first agriculture and later residential development. Native desert vegetation has given way to mostly non-native species maintained by irrigation, affecting biodiversity at higher trophic levels. This context has provided fertile ground for SES research on land-use and land-cover change, climate-ecosystem interaction, water use, altered biogeochemical cycles, and biodiversity.

Impacts

- Advancing understanding of urban ecological systems: CAP participants have published 344 journal articles, books, and book chapters since project inception in 1997 (Fig. 2).
- Contributions to higher education: Over 100 graduate students have served as project participants, including 41 fellows in the Integrative Graduate Education and Research Traineeship (IGERT) in Urban Ecology, which is housed in ASU's Global Institute of Sustainability (GIOS), also the home of CAP. Over 100

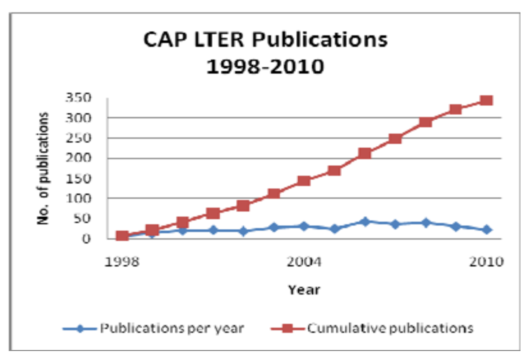

Figure 2. Annual and cumulative publications, 1998-2010.

undergraduate students have been involved in CAP since 2004: 81 as student workers on research and education initiatives, 19 as Research Experience for Undergraduates students, and one as a fellow of the Ecological Society of America's Strategies for Ecology Education, Development, and Sustainability.
- Leveraged funding for research: Nearly $40 million in leveraged funding from CAP LTER since 1997 has created a rich interdisciplinary community at Arizona State University (ASU) focused on urbanization and sustainability in central Arizona and beyond. Of that total, half has accrued during CAP2.
- K-12 outreach: CAP LTER's program at the K-12 level, Ecology Explorers, has over 100 teacher-participants at 100 public schools (encompassing 25 school districts), 2 charter schools, and 1 private school.
- Community outreach: 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 several local municipalities. Details on our education and outreach efforts appear in sections VI and VII of this report.

Transformative Research

1. CAP LTER has developed new theory and knowledge at the intersection of ecology and social science research that has changed the way people – including scientists – perceive the natural environment in the city.

For most of ecology's history as a discipline, the focus of study was on pristine, wildland sites. Urban areas were seen as human-disturbed places less worthy of investigation. Urban ecology experienced a paradigm shift in the latter part of the 20th century, when it began to focus on the structure and function of cities as ecosystems. The establishment of two long-term ecological research sites in the Phoenix and Baltimore metropolitan areas in 1997 lent credibility to the study of urban ecosystems.

CAP LTER has been a leader in a burgeoning understanding of urban socio-ecological systems, and by extension, the broad integration of social science into ecological studies. In the process, CAP has led a transformation of education and graduate training that truly integrates disparate disciplines with an emphasis on problem-solving in cities. This transformation has extended to K-12 education through our award-winning Ecology Explorers program.

2. CAP climate researchers and social scientists discovered that the extent to which neighborhoods are affected by extreme heat varies according to both physical and demographic characteristics.

The Urban Heat Island Effect (UHI) is when a city is significantly warmer than the outlying rural area due to the preponderance of concrete and asphalt surfaces that store heat during the day and release it at night. While urban heat islands exist in most large cities, the Phoenix metropolitan area has presented a special case for the study of this phenomenon because of its rapid growth over the last 30 years and the already high summertime temperatures experienced in the valleys of the Sonoran Desert.

The emergence and intensification of Phoenix's UHI represents an important stressor on humans in the city. CAP researchers found that the UHI varies greatly in space, mirroring the physical heterogeneity of the urban landscape. Variations in amounts and distributions of soil, impervious surface, and vegetation in urban and suburban areas can either exacerbate or ameliorate the UHI. Superimposed on this are spatially variable demographic characteristics of the human population. As a result, extreme temperatures are distributed unevenly among neighborhoods, with minority, low-income, and elderly residents at greatest risk for exposure to high heat.

3. Understanding how urban ecosystems function provides knowledge to urban planners who design urban systems for public benefit.

Ecosystem services are the benefits that people receive from their life-supporting environment. These include the "goods" that nature provides to us (i.e. food, water, fiber, energy) as well as soil fertility, air and water quality, pest control, recreation, and aesthetics. Natural systems deliver these services, but humans have also designed or engineered ecosystems to deliver specific services. This ecosystem design is a particular characteristic of cities.

CAP research has found both intended and unintended ecosystem services associated with highly engineered aquatic systems in the urban environment (e.g., systems for water delivery, storm water removal, and wastewater processing). Parks along a flood "greenway," such as Indian Bend Wash in Scottsdale, Arizona, are an excellent example. In addition to their obvious recreational value and capacity to absorb or convey floods, these parks are also efficient at removing nutrients and contaminants from floodwater. Retention basins, established for flood management, double as recreational spaces and nutrient removal systems. Other engineered aquatic ecosystems, however, do not provide benefits beyond those for which they were originally designed (e.g. concrete stormwater spillways). Awareness of the potential benefits of ecosystem functions increases the potential for urban planners and policymakers to design systems that optimize the ecosystem services delivered to the public.

4. Using long-term data sets, CAP research has extended tests of plant and animal diversity theory to urban environments where people's choices and actions are pervasive.

Most ecological theories are based on ecological patterns and processes in non-urban and less human-dominated environments. As cities grow and the global population becomes more urban, ecologists need to test their theories in urban settings and modify them, or even develop new ones, to reflect the ecology of cities.

CAP scientists have used the special characteristics of urban food webs (i.e. trophic dynamics) to test long-standing ecological theories about organismal interactions, biodiversity, and the assembly of communities. In particular, diversity patterns of birds and some arthropods in urban ecosystems suggest that exotic and invasive species associated with human settlements (e.g. pigeons and grackles) often outcompete native species that could otherwise inhabit cities. In Phoenix, the diversity of plants is actually higher in the city compared with the surrounding Sonoran desert ecosystems because people have introduced many native species to create the desert "oasis city." Long-term data sets have allowed CAP researchers to investigate these changes over time as the Phoenix metropolitan area has grown.

5. **LTER investigations across urban sites in the Phoenix, Baltimore, and Boston metropolitan areas have revealed that household decision-making and income influence species diversity in residential landscapes.**

Residential landscapes are a critical ecological feature of the urban ecosystem because they are widespread and are made up of highly designed and managed combinations of plants (e.g., landscaping) and animals (e.g., pets). For example, as Phoenix has urbanized, native Sonoran desert ecosystems have been replaced by an "urban oasis" that includes both lush, watered lawns and carefully managed desert-like landscapes. CAP's socio-ecological research evaluates the household decision-making, perceptions, and priorities that result in particular residential landscapes.

LTER research at the CAP, BES, and PIE sites reveals numerous complex interactions between social and ecological systems that occur at the scales of households and neighborhoods. Researchers have shown that: 1) household income is correlated with plant and bird diversity; 2) people tend to manage their front yards and back yards differently due to social considerations, and 3) preferences and attitudes for residential landscapes depend, in part, on history, gender, culture, and economics.

II. Research Activities

Research Design and Approach

In CAP2, we continued our focus on the following research question:

How do the patterns and processes of urbanization alter the ecological conditions of the city and its surrounding environment, and how do ecological consequences of these developments feed back to the social system to generate future changes?

Conceptual Framework

Our characterization of the central Arizona SES remains grounded in a hierarchical, patch-dynamics framework that originated in landscape ecology (Wu and Loucks 1995; Grimm et al. 2000; Wu and David 2002). Spatial heterogeneity and distributions of biophysical *and* social variables are critical to our approaches for understanding how metro Phoenix is changing. Furthermore, scaling of human and ecological phenomena over space and time are featured prominently in many CAP projects (Jenerette et al. 2006; Buyantuyev and Wu 2007; Ruddell and Wentz 2009). Thus, our conceptual framework for an urban SES is dynamic, potentially multiscalar, and describes socioecological interactions within parts as well as for the whole heterogeneous system (Fig. 3). Specific models, such as those predicting atmospheric deposition or effects of the Urban Heat Island (UHI) on ecosystem processes also fall within this framework. The framework builds upon that proposed for the LTER network initiative (ISSE; Collins et al. 2007) and shares themes with frameworks in sustainability science (MEA 2005; Chapin et al. 2006; Carpenter et al. 2009). Its components are: drivers, space and time scales, ecosystem structure and function, ecosystem services, and human outcomes and actions.

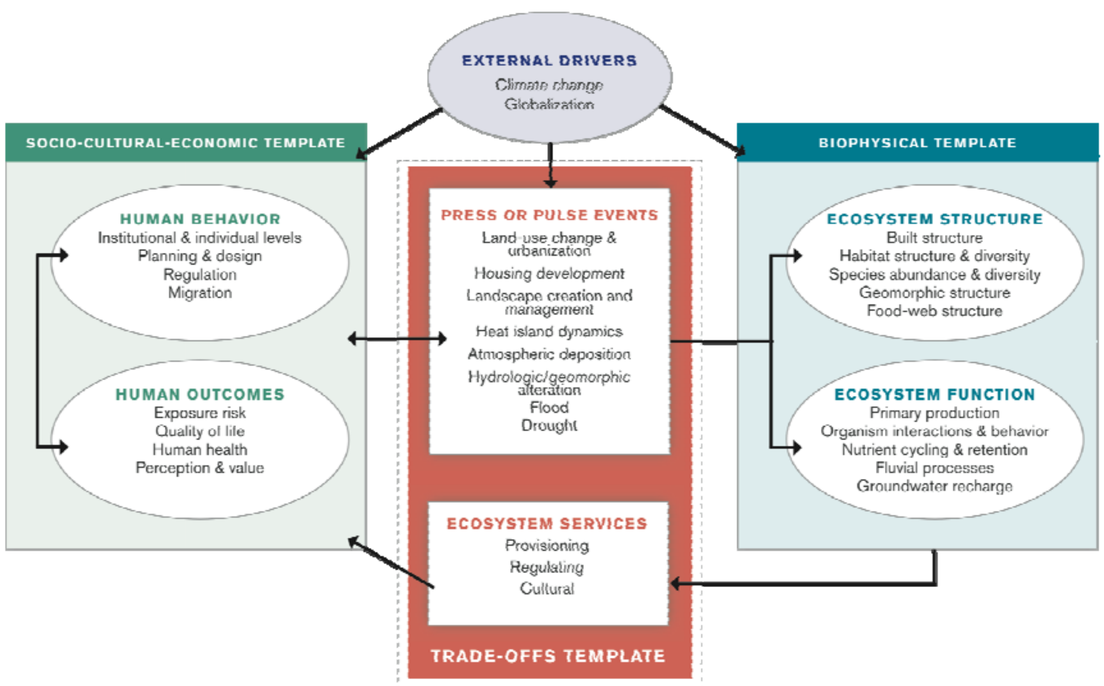

Figure 3. In CAP2, we adopted a slightly modified version of the Integrative Science for Society and the Environment (ISSE) conceptual model (Collins et al. 2007) as an expression of our conceptual framework for understanding urban socio-ecological systems.

Integrative Project Areas

A particular strength of the US LTER program is consistency of measurement in the five, broad core areas. However, during CAP1, we found that organization of projects and working groups under the traditional LTER core areas does not necessarily facilitate interdisciplinary integration (Redman et al. 2004). Therefore, we identified five Integrative Project Areas (IPAs) to organize our research. The major objectives and/or questions of each IPA are as follows.

- **Land-Use and Land-Cover Change (LULCC)**

Land use and land cover define the context of the socio-ecosystem, and alterations in their patterns represent some of the most seminal changes to the system. We ask: How have land use and land cover changed in the past, and how are they changing today? How do land-use and cover changes alter the ecological and social environment in the city, and how do human perceptions of these changes alter future decision-making? This understanding, in turn, sets the stage for all other IPA research.

- **Climate-Ecosystem Interactions**

Climate is an important driver of processes in most ecosystems. The spatial and temporal dynamics of human actions both deliberately (irrigation) and inadvertently (urban heat island) modify the urban climate. Studies of climate-ecosystem interactions will be conducted at multiple scales from single organism to regional. We ask: How does human-driven, local climate change compare with longer-term trends and/or cycles of climate in the region? How do regional drivers influence local climate as urbanization proceeds? What are people's perceptions of their local environment, including climate, and how does that affect their assessment of neighborhood or regional quality of life? What are the interactions among local management, local climate, net primary production (NPP) and vegetation processes?

- **Water Policy, Use, and Supply**

Humans now appropriate 100% of the surface flow of the Salt River and are increasingly exploiting groundwater resources and surface waters from more distant basins (e.g., Colorado River). Controlled management and engineering shift the characteristic spatial and temporal variability of the hydrologic system. What are the ecological and economic consequences and potential vulnerabilities of those shifts? What institutional responses best address those vulnerabilities? Within this IPA, we examine landscape water management, water supply and delivery, riparian restoration, and resilience of the socio-ecosystem to water-related stress or catastrophe.

- **Fluxes of Materials and Socio-Ecosystem Response**

Material fluxes and biogeochemical linkages have been studied for decades in relatively undisturbed ecosystems, but not in urban ecosystems where human-generated fluxes of nutrients and toxins are coupled with nonhuman biogeochemistry. The main question driving the ecological research in this IPA is: How do urban element cycles differ qualitatively and quantitatively from those of nonhuman-dominated ecosystems? Nutrient, pollutant, and toxin element cycles drive our main sociological questions: What are the socio-spatial 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 decisionmakers accurately perceive these hazards?

- **Human Control of Biodiversity**

Ecological approaches to studying human control of biodiversity have typically focused upon habitat loss and disturbance brought about by humans at high population densities. We will move beyond these approaches to ask: How do human activities, behaviors, and values change biodiversity and its components—population abundance, species distribution and richness, and community and trophic structure? In turn, how do variations in biodiversity feed back to influence these same human values, perceptions, and actions?

Crosscutting Research

Ongoing research activities include those that cut across and contribute to several IPAs, such as the **Survey 200**, extensive sampling conducted every five years; the **NDV Experiment**; and the neighborhood-scale **PASS.** Appendix B lists the full suite of CAP's long-term monitoring endeavors. Although sampling and analysis activities from these crosscutting projects often are carried out as a unit, the findings from these research endeavors are integrated into IPA research and are reported as such.

Survey 200. The Survey 200 is an extensive field survey that provides a snapshot of broad-scale spatial variations in key ecological variables across the CAP region. Designed to be repeated every five years, it also is a central component of CAP's monitoring of ecosystem change over time. The survey has been carried out in 2000, 2005, and 2010 (data entry to be completed in December 2010) and has included the following core measurements:

- Plants identified to species
- Plant size measurements for biovolume calculations
- Mapping of built and vegetation structures
- Soil coring for physicochemical analyses
- Insect sweep-net sampling

Survey 200 data from both the 2000 and 2005 surveys have been used in numerous studies by CAP scientists (Hope et al. 2003, 2005, 2006; Oleson et al. 2006; Stuart et al. 2006; Zhu et al. 2006; Dugan et al. 2007; Kaye et al. 2008; Majumdar et al. 2008, *in press*, *in review*; Majumdar and Gries 2010; Walker et al. 2009). Among the recent work with the Survey 200 data is an analysis of the five main carbon pools (trees, shrubs, cacti/succulents, herbaceous vegetation, and soil) for each of the 200 point survey locations, using Kaye et al.'s (2008) methods (hierarchical Bayesian scaling) to understand the spatial dynamics of carbon storage pools across the Phoenix metropolitan area. Researchers initially are using the 2005 data set but intend to eventually evaluate the 2000 data and analyze change over time and use these data to construct a carbon budget for the CAP ecosystem. Other ongoing work, described in previous reports, examines heavy metals in Phoenix area soils. This report details some initial findings of investigations of black carbon in Survey 200 soils.

The NDV Experiment. The NDV community landscape experiment at ASU's Polytechnic campus is designed to give a platform for CAP LTER researchers to study human–landscape interactions. 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 study area (Martin et al. 2003; Cook et al. 2004). 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.

- Native: native Sonoran Desert plants on granite substrate and no supplemental water.

Six additional households are monitored as no-plant, no-water controls. Major research questions include: *How do landscape design and irrigation methods affect NPP and under-canopy microclimate, soil nutrient pools and fluxes, insect abundance and diversity, bird activity?, and how does landscape design affect direct human-landscape interactions in terms of both perceptions and behaviors?*

During summer 2005, CAP completed the landscape and irrigation systems for each of the treatment areas. During spring 2006, technicians installed micrometeorological stations in the central common area of each treatment. Data continually monitored include soil temperature, soil heat flux, and volumetric water content of soil at 30 cm depth. Air temperature at 2 m height and soil-surface temperature (recorded by an infrared thermometer at 2 m height) are also monitored regularly. Instrumentation records landscape irrigation application volumes monthly.

Researchers have analyzed data from the pre-treatment social survey and have published findings from this round of research (Casagrande et al. 2007; Larson et al. 2009; Yabiku et al. 2008). The follow-up social survey began in spring 2006 and continued through summer and fall 2006. Researchers are continuing to analyze data from this survey to compare it with the pre-treatment survey.

The NDV research team continues work on an integrated project focusing on ecosystem services of landscape treatments at NDV. Using data from a variety of sources, including infrared surface temperature measurements, the researchers will analyze which of the four NDV landscapes optimizes the trade-offs between the following ecosystem services:

- temperature moderation and energy use
- water use
- aesthetics and quality of life
- carbon sequestration

This research will contribute to an academic and public dialogue about the values of various landscape types in the Phoenix area. While water conservation advocates have pressed for the conversion of mesic to xeric landscapes, this research will illuminate the energy-water tradeoffs in such a conversion.

Phoenix Area Social Survey (PASS): In 2001, eight social scientists and one biophysical scientist, all affiliated with the CAP LTER, conducted a pilot social survey of 302 residents in eight neighborhoods in Phoenix (Kirby et al. 2006; Larsen and Harlan 2006; Harlan et al. 2009). The goal of the study was to increase understanding of how human behavior shapes the dynamics of an urban socioecosystem. PASS parallels the Survey 200 as a major component of our long-term monitoring program. Following the pilot study, CAP received two supplemental NSF grants in 2004 to enlarge the sample and continue the social survey. The NSF-funded Decision Center for a Desert City (DCDC) made an additional financial contribution to the study. Subsequent surveys, conducted every five years, will be part of CAP's core budget.

An expanded team of 20 CAP LTER and DCDC social and biophysical scientists, academic professionals, and graduate students designed the second wave of the PASS in 2005. PASS survey questions engage human perceptions, values, and behaviors concerning the environmental domains emphasized in the IPAs and the focal interests of DCDC:

- Water supply and conservation
- Land use, preservation and growth management
- Air quality and transportation

- Climate change and the urban heat island.

In addition, the survey continues to question residents about community sentiment and perceptions of their neighborhood social, built, and biophysical environments. The intellectual goals of PASS are to help us address the following questions: *How do human communities form, adapt, and function in a rapidly urbanizing region? How do human knowledge, values, and preferences affect behaviors that transform the preexisting ecosystem into an urban landscape? How do spatial variations in ecosystem characteristics relate to social class inequalities and cultural differences across the urbanizing area? How do changes in social, economic, and environmental systems affect the quality of life and vulnerability to environmental hazards for diverse human populations?*

The survey team conducted the PASS in spring 2006 with respondents comprising residents from 800 randomly selected households in 40 neighborhoods that are co-located with Survey 200 field sites. The summary report of the survey can be found at http://caplter.asu.edu/docs/contributions/2007_PASS2.pdf.

Since that time, researchers have analyzed PASS data and drafted numerous publications. These include works that explore urban growth (York et al. in prep.), scale and perceptions of climate change (Ruddell et al. in review), vulnerability and urban heat (Ruddell et al. 2010), gender and water policy (Larson et al. *in press*), migration and health (Yabiku et al. 2009) and cultural domains and water (Larson et al. in prep.). Additional studies conducted in concert with the PASS include the Phoenix Ethnohydrology Study (Crona et al. in review), a comparison of responses on water resource sustainability among the lay public, ASU scientists, and Phoenix-area policymakers (Larson et al. 2009a.), and a study of avian biodiversity and social variation (Lerman et al. *in review*).

III. Highlights of Research Findings

Land-Use and Land-Cover Change (LULCC)

Alterations in patterns of land use and land cover underlie many ecological changes in the urban SES and central Arizona. In CAP2, analysis of remotely sensed data showed ongoing rapid urbanization (Buyantuyev and Wu 2007; Buyantuyev et al. 2007; Walker and Briggs 2007) superimposed on centuries of land use. Distinctive silt deposits and associated plant communities along desert washes are legacies of prehistoric agricultural fields of the Hokoham culture over 1,000 years ago (Briggs et al. 2007; Schaafsma and Briggs 2007; Fig. 4). Since 1970, rapid urbanization has led to a decline of arable land and a rise in urban (residential) land uses (Keys et al. 2007). Despite this change, legacies of historic (i.e., <150 years) agrarian practices remain (Redman and Foster 2008) and can influence contemporary soil biogeochemical pools and fluxes (Lewis et al. 2006; Hall et al. 2009). Land-use legacies are one of several human influences on the structure and properties of contemporary residential landscapes. Myriad decisions, values, and norms expressed at the household, neighborhood, and regional scales drive management of residential landscapes (Larson et al. 2008). Effects of residential development decisions may last long into the future and become institutionalized by Homeowner Associations' Covenants, Codes and Restrictions (Martin et al. 2003).

At the regional scale, understanding institutional drivers of urban growth is critical because urban sprawl has economic, ecological, and social repercussions. We analyzed ballot propositions associated with state-trust land and found that conservation and development concerns are rising as priorities along with issues of land management and resource use (York et al. in review). In our LTER cross-site (CAP, JRN, SEV, SGS, KNZ) land-fragmentation study, we ask how urban-population dynamics, water provisioning, transportation, amenity-driven growth, and institutional factors influence patterns of land fragmentation. Early results suggest strong similarities in land fragmentation patterns among Phoenix, Albuquerque, and Las Cruces (both in New Mexico) as suburbs expanded outward (York et al. *in press*; Fig. 5).

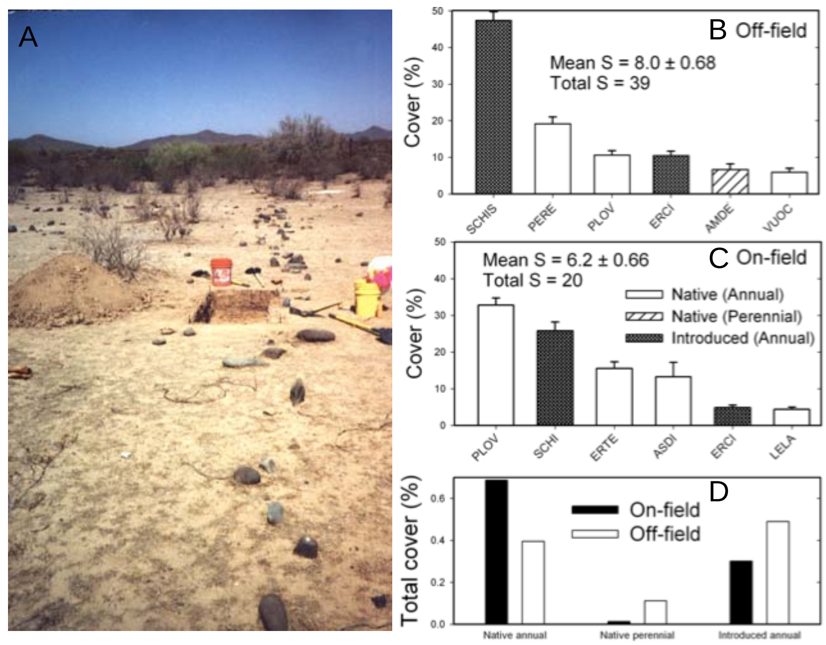

Figure 4. (A) One of the prehistoric agricultural fields at Cave Creek during the dry season, showing rock alignments (the remnants of a Hohokam water control feature for an irrigation canal). (B, C) Mean cover (±standard error) of the six dominant species in $0.25m^2$ quadrats located on and off prehistoric agricultural fields at Cave Creek. (D) Growth form and origin (native versus introduced) of vegetation in $0.25m^2$ quadrats placed on and off prehistoric agricultural fields at Cave Creek, expressed as percentage of total cover. Note that while native annual species composition on and off the fields is almost identical, the percentage of introduced annual vegetation was higher on the prehistoric fields than in adjacent off-field areas. (Mean S = mean species richness; Total S = total species richness. SCHI = *Schismus* sp, PERE = *Pectocarya recurvata*, PLOV = *Plantago ovata*, ERCI = *Erodium cicutarium*, AMDE =*Ambrosia deltoidea*, VUOC = *Festuca octoflora*, ERTE = *Erodium texanum*, ASDI = *Astragalus didymocarpus* and LELA = *Lepidium lasiocarpum*). From Briggs et al. 2006.

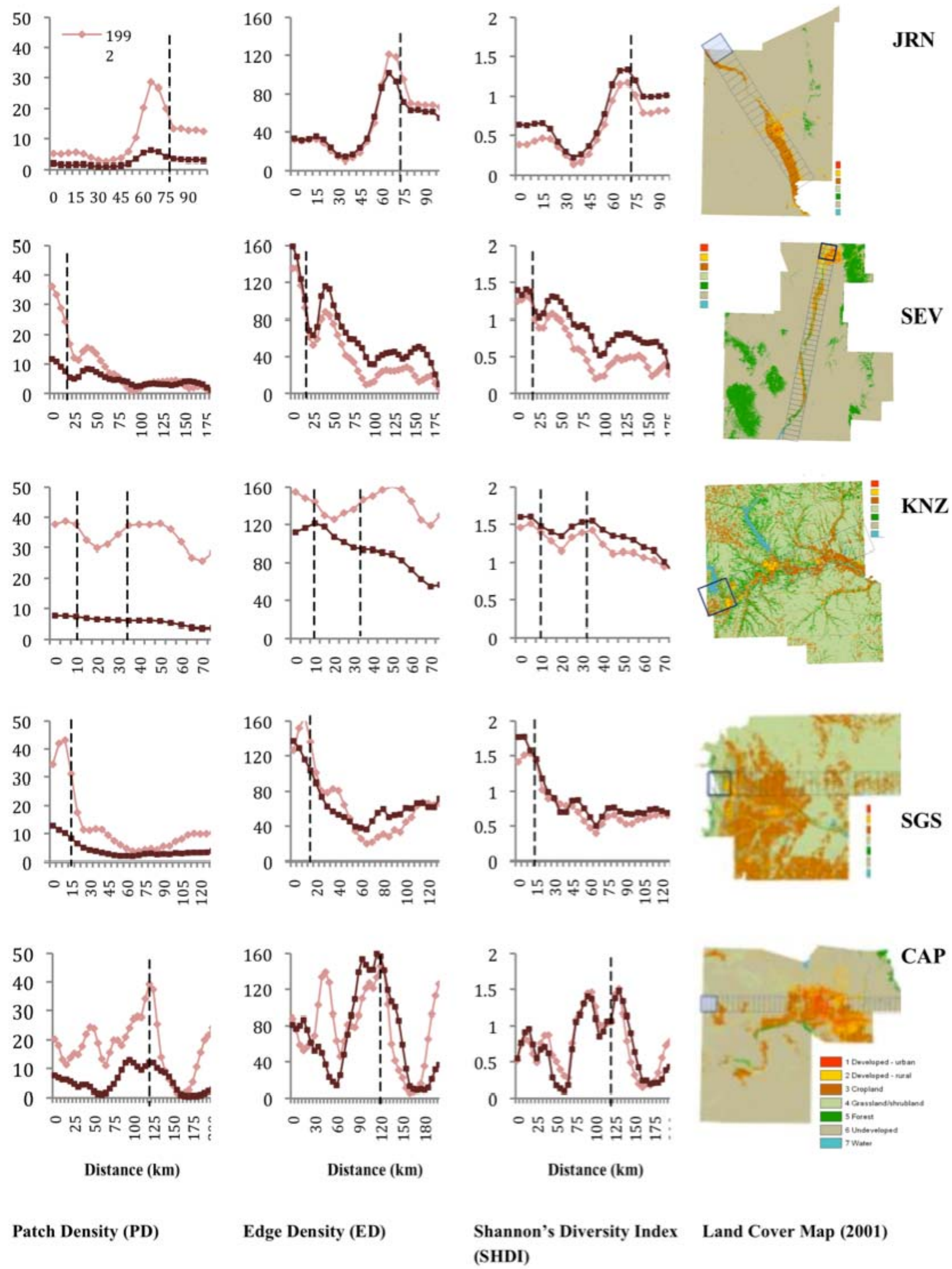

Figure 5. Spatial distribution of different landscape metrics at the landscape level along transects (shown on maps at right) for five LTER sites in 1992 and 2001.

Climate-Ecosystem Interactions (CLIM-ECO)

Climate is an important driver of ecosystem processes (e.g., primary production) and human outcomes (e.g., health and quality of life). In CAP1 and CAP2, we characterized the Urban Heat Island (UHI) (Hedquist 2005; Hartz et al. 2006a, b; Sun et al. 2009), a phenomenon where nighttime temperatures have increased up to 5°C in the past several decades. Temperature changes already occurring in the CAP study area overwhelm any global climate-change signal, thus CAP and other urban systems present microcosms of the effects we might see with global climate change (Grimm et al. 2008b).

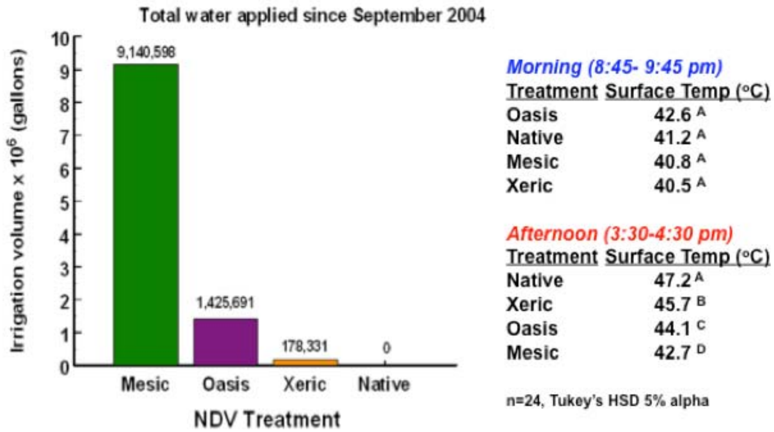

Figure 6. Data illustrating the tradeoffs inherent in using outdoor vegetation to ameliorate the UHI. Left, water application to experimental treatment landscapes; right, house surface temperature in the morning and mid-afternoon on a hot July day. Mean temperatures with the same superscripts are not significantly different. C. Martin, unpublished.

In CAP2, we probed causes and consequences of spatial variability in the UHI across the urban landscape. Local temperature exhibits strong relationships with land-use and land-cover characteristics (Myint and Okin 2009), and heat loads to homes are associated with vegetation amount and type in our experimental landscapes (Fig. 6). Varying amounts and distributions of soil, impervious surface, and vegetation in urban and suburban areas exacerbate or ameliorate the UHI. Grossman-Clarke et al. (2008) modified the Mesoscale Meteorological Model (MM5), showing that urban landscape heterogeneity strongly impacts weather patterns.

The UHI has environmental-justice implications, because spatial heat variability affects some segments of the population more than others (Harlan et al. 2006; Jenerette et al. 2007; Harlan et al. 2008). Using temperature simulations for the July 2006 heat wave, we showed that extreme temperatures were variably distributed over Phoenix neighborhoods. Furthermore, residents' perceptions of temperature and self-reported, heat-associated illnesses were related to neighborhood environmental conditions (e.g., vegetation, Gober et al. 2010). Residents at greatest risk of exposure to heat tended to be minority, low-income, and elderly (Ruddell et al. 2010; Ruddell et al. *in review*).

Urbanization and the UHI also affect plant phenology. Changes in plant population and community dynamics may result from a significant change in flowering phenology for a small but substantial proportion of the flora (Neil and Wu 2006; Neil et al. 2010; *in review*). Our urban sites also showed a decoupling of phenology from precipitation, the main driver of phenologic change in the desert (Fig. 7). Phenology of urban vegetation instead appears linked to specific ecosystem services, such as food and fodder production, recreation, or cultural aesthetics (Buyantuyev and Wu 2009).

Water Policy, Use, and Supply (WATER)

The Phoenix metropolis now appropriates 100% of the surface flow of the Salt River, which once flowed through Phoenix, and is increasingly exploiting local groundwater and surface water from more distant basins (e.g., the Colorado River). Controlled management and engineering have dramatically shifted the spatiotemporal variability of the hydrologic system. For example, we found that annual sediment transport dropped to low levels in fully urbanized portions of the region (El-Ashmawy et al. 2009). CAP2 research was closely integrated with that of the Decision Center for a Desert City (DCDC, a NSF-funded DMUU Center) through several projects on water dynamics jointly supported by the two programs.

In aridland cities, human control and consumption of water resources influence the sustainability of the urban system and its biota. For example, mass balances for water and salt in the City of Scottsdale show precipitation to be the largest single source of water into the city, a surprising result given that the area annually receives only 180 mm of rainfall, pumps 29,000 acre feet of groundwater, and depends on surface water from the Salt and Colorado rivers (Westerhoff and Crittenden 2009). Salts become trapped in the vadose zone, threatening the long-term sustainability of the human-controlled hydrologic system in this and other cities (Westerhoff and Crittenden 2009).

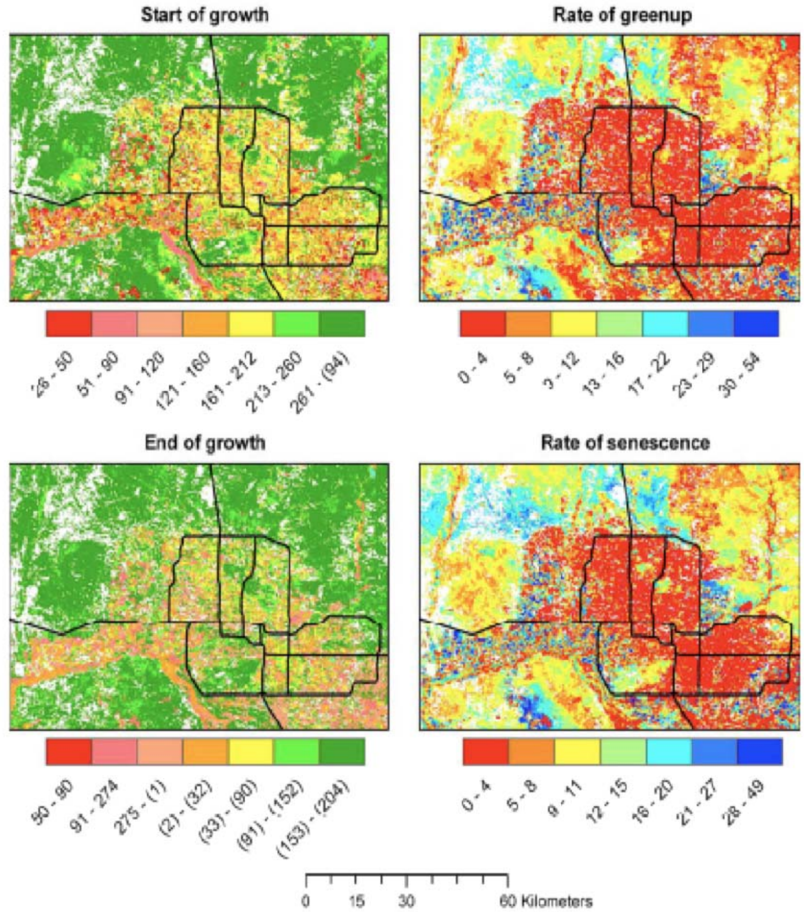

Figure 7. Seasonal parameters extracted from Savitsky-Golay filtered NDVI data. Start and end dates, rate of growth and senescence of the first growth period during 2004-2005. Dates are displayed as days of year (year 2005 days are shown in parentheses). Rates are calculated as tangent of slope between 20% and 80% levels of NDVI.

Water use, vegetation, cooling, and inequitable UHI distribution provide an excellent example of ecosystem-service tradeoffs we will examine in greater detail in CAP3. Outdoor irrigation accounts for most of the water used by Phoenix area households and, in turn, water use directly relates to affluence (Harlan et al. 2009). Lifestyle preferences and priorities embodied in outdoor landscaping help explain the preference for water-intensive lawns and outdoor features (Larsen and Harlan 2006; Yabiku et al. 2008), as do socially constructed ideas about nature and its place in the urban environment (e.g., “I think the desert belongs in the desert”; Larson et al. 2009a). Vegetation helps to ameliorate heat intensity (Stabler et al. 2005; Jenerette et al. 2007; Martin 2008), but this ecosystem service requires water. Unequal access to heat-ameliorating landscapes accounts for spatial variability in vulnerability to the UHI.

In conjunction with DCDC, we asked how policies and decisions about water are made in Phoenix. A steady weakening of the Groundwater Management Act of 1980, designed to attain “safe-yield” of groundwater, has heightened water insecurity and delayed conservation measures (Hirt et al. 2008; Larson et al. 2009b). We found that policymakers were significantly less concerned than the lay public or scientists about regional water-use rates; the lay public tended to blame other people for water scarcity and scientists stressed the need to control demand (Larson et al. 2009c).

Material Fluxes and Socioecosystem Response (FLUXES)

Material fluxes and biogeochemical linkages underlie most ecological processes, but in urban ecosystems they are overwhelmed by human-generated fluxes of nutrients and toxins, and by design and management influences on timing, duration, and magnitude of biogeochemical processes (Kaye et al. 2006). Our biogeochemical studies have been conducted from plot/parcel scales to watershed/whole-system scales, including interaction with surrounding ecosystems, and we consider air, water, and people to be key biogeochemical transport vectors (Peters et al. 2008).

Storms provide water that stimulates biogeochemical processes and mediates transport in ephemeral desert streams (Harms and Grimm *in press*). Built structures or management may ameliorate or exacerbate these processes. Indian Bend Wash (IBW) in Scottsdale is a designed stream-lake floodway influenced alternately by management and natural hydrologic variation (Roach et al. 2008; Fig. 8). The identity of the limiting nutrient (nitrogen [N] or phosphorus [P]) varies temporally in response to deliberate water additions (high in N) or natural flood inputs (high in P; Fig. 8; Roach and Grimm 2009). Stormwater management in this aridland city features designed systems—retention basins, floodplain parks, and “restored” riparian zones—that provide a diversity of ecosystem services, some intentional and some not (E. Larson et al. *in review*; Fig. 9). Our studies of organic carbon (oC) sources to Tempe Town Lake, a constructed urban lake, show seasonal variations confirmed by chemical signatures of different flow components from the

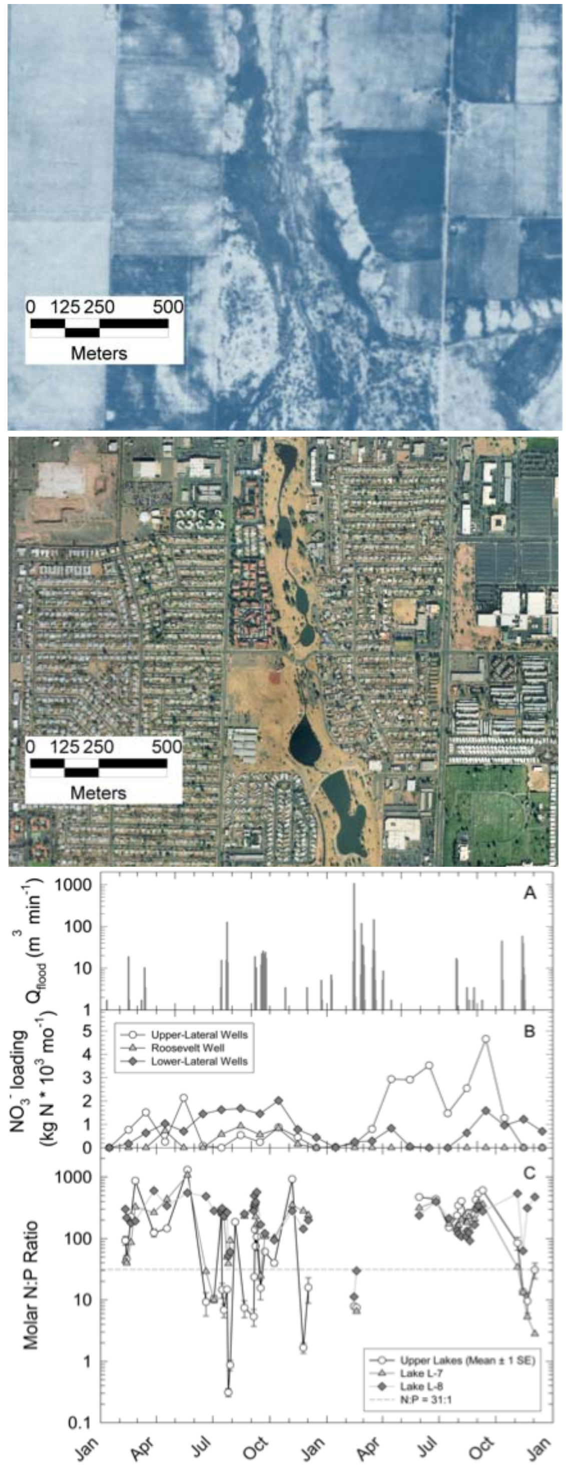

Figure 8. Change in ecosystem structure (photos) between 1949 and 2000 in IBW. Nutrient loading (B) and N:P (C: indicative of nutrient limitation) show dramatic shifts associated with storms (discharge increases in A).

major riverine sources (McLean 2007). At smaller spatial scales, variation in N transport is sensitive to

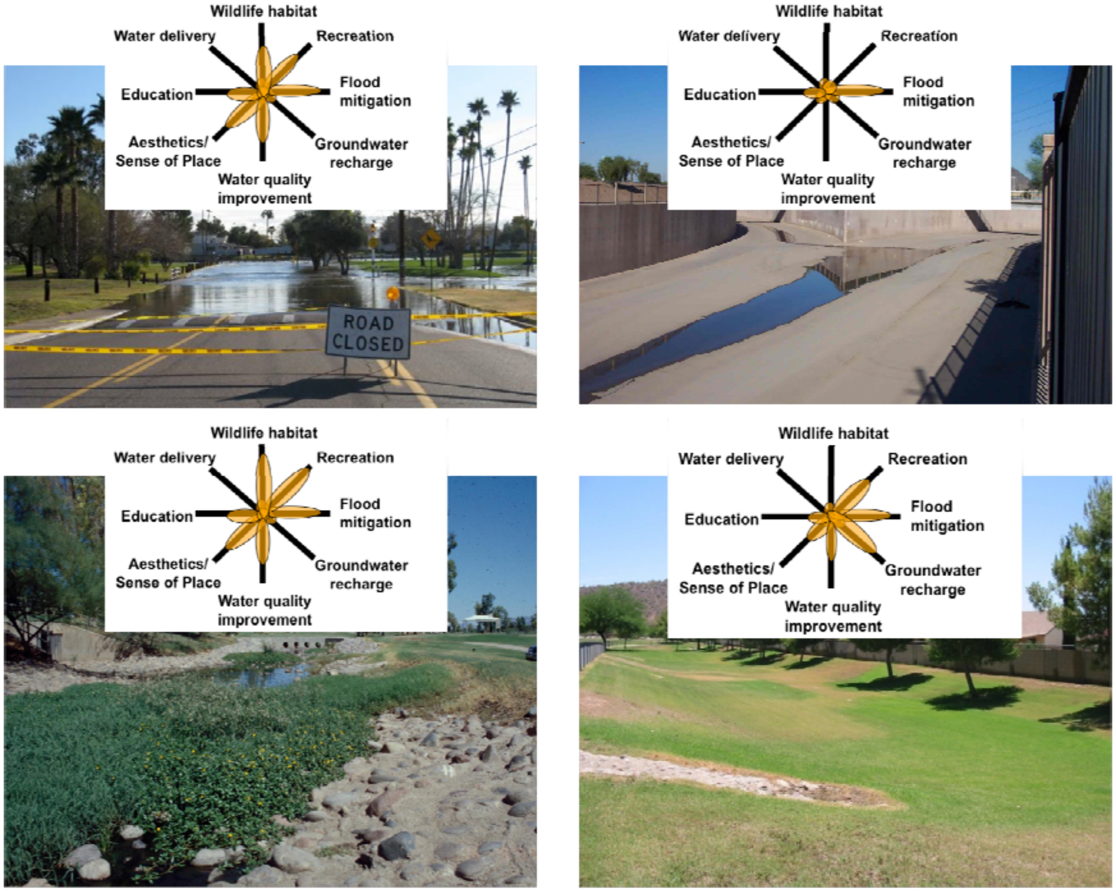

Figure 9. Photos of various stormwater management systems in metro Phoenix, with a conceptualization of the range of ecosystem services they provide (insets). Clockwise from top left: IBW floodway at a road crossing; flume design for stormwater removal; a mesic stormwater retention basin; and IBW at a golf course site. After E. Larson et al. (in review).

a combination of catchment features and storm characteristics (Lewis and Grimm 2007). This research collectively supports an original CAP hypothesis that urbanization increases spatial heterogeneity of nutrient transport, but it also begins to uncover the responsible mechanisms.

Our research on atmospheric transport and deposition has found relatively low annual rates of wet and dry N deposition that did not differ significantly across an area larger than the CAP study region. In contrast, wet and dry deposition of oC was significantly elevated in the urban and downwind desert compared to upwind sites (Lohse et al. 2008). We have found no effect of atmospheric N and oC fertilization on primary production of perennials, although annuals show a response to supplemental N additions when rainfall is sufficient (Fig. 10).

CAP's extensive soil survey (see Section III.A.3) provides a foundation for understanding controls on and impacts of the spatial distribution of nutrients, oC and inorganic C (iC), black C (bC), and metals. Urban soils have significantly higher bC contents (Fig. 11) than desert soils, and soil concentrations of lead (Pb), cadmium (Cd), copper (Cu), and arsenic (As) are correlated with urbanization (Fig. 12). Urban Pb isotopes showed that the source of this metal was either leaded paint or western coal, but not leaded gasoline. We used hierarchical Bayesian models to scale plot data on oC, iC, N, and P to the 6400-km^2 CAP region (Fig. 13) and estimated that 1140 Gg of oC and 130 Gg

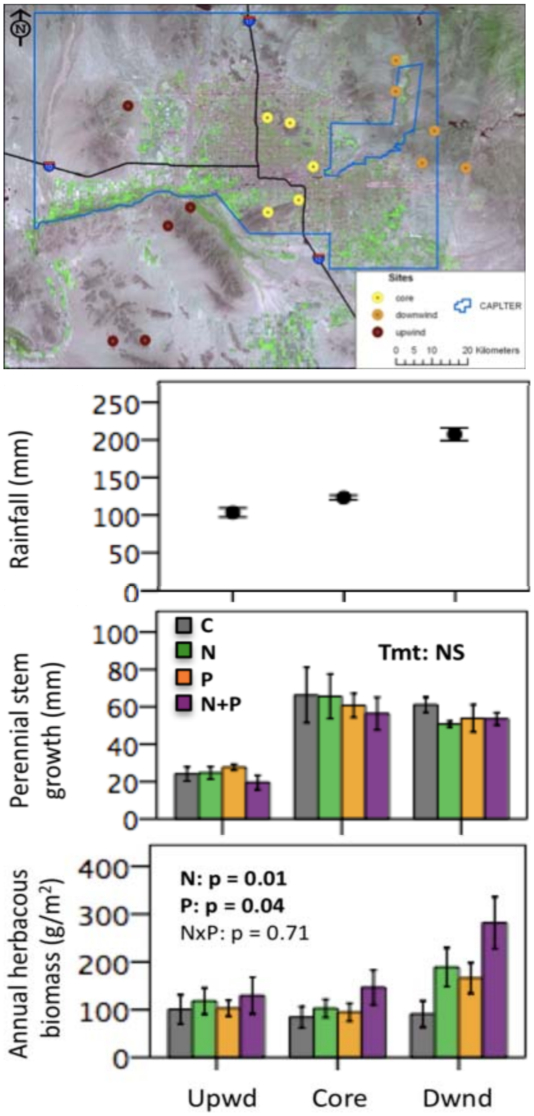

Figure 10. Response of perennial and spring annual Sonoran Desert plants to experimental nutrient additions in sites across the Phoenix metropolitan area. Data shown for Spring 2008. C = Control; N = NH_4NO_3 addition; P = PO_4^{-3} additions as triple superphosphate; N+P = N and P in combination. Fertilization began in December 2005. N = 5 sites per region.

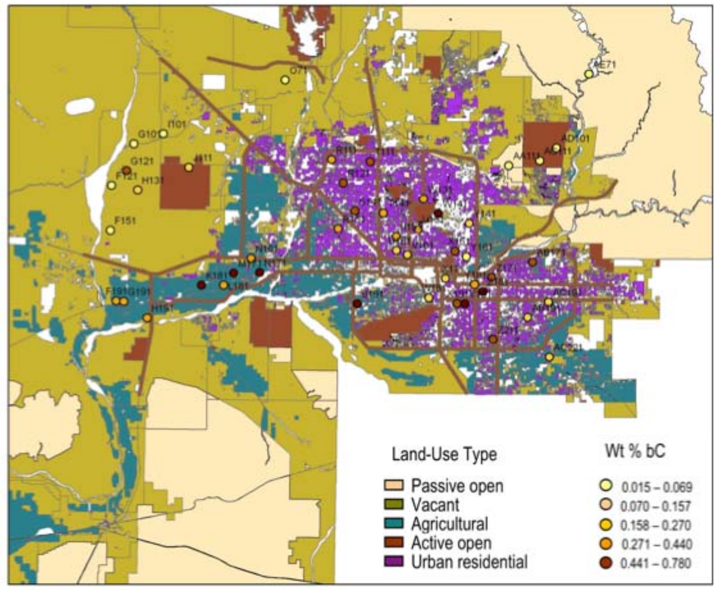

Figure 11. Distribution of bC across the CAP study area. Locations (circles) of soil survey sites are color-coded with darker shading indicating higher bC contents. Color overlays are general land-use classifications identified by Maricopa Association of Governments. H. Hartnett, unpublished.

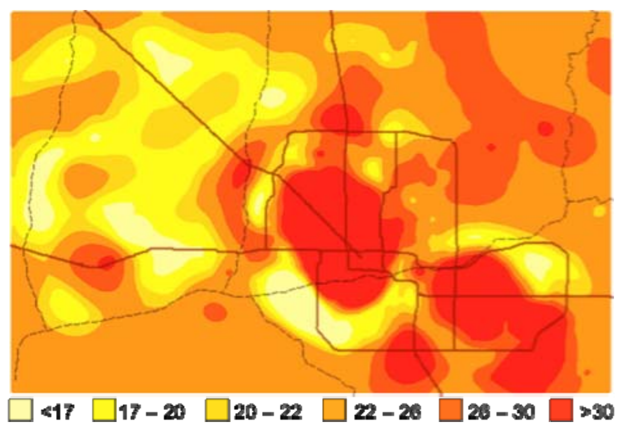

Figure 12. Lead concentration (µg/kg) measured in 2005 in the surface soil (1–10 cm) across CAP. Brown lines show major freeways; the urbanized region is encircled by these roads.

of N have accumulated in urbanized soils of the region (Kaye et al. 2008; Majumdar et al. 2008), comparable to values estimated previously (Hope et al. 2005; Zhu et al. 2006). This work also confirmed that land-use legacies (i.e., whether a site had ever been farmed) were important determinants of soil-nutrient concentrations.

Distributions of materials also result in uneven distributions of disamenities (environmental factors that negatively affect people) across the CAP region, with ensuing environmental-justice

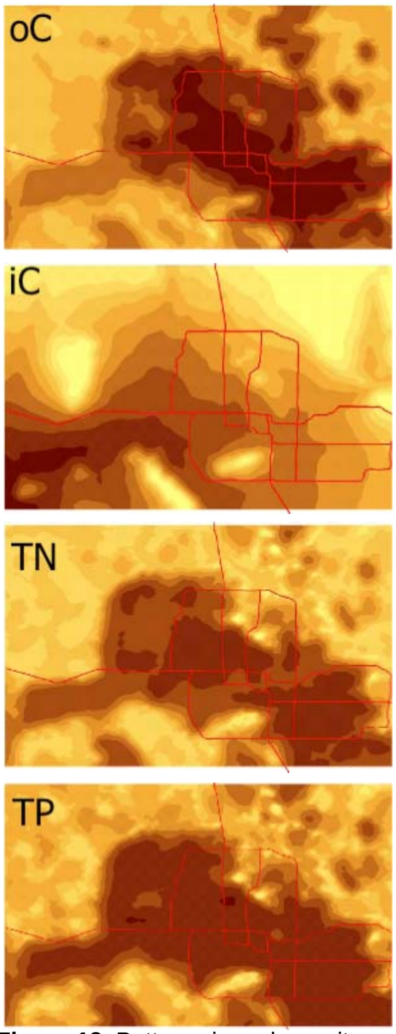

Figure 13. Patterns in carbon, nitrogen, and phosphorus across CAP. From Kaye et al. (2008).

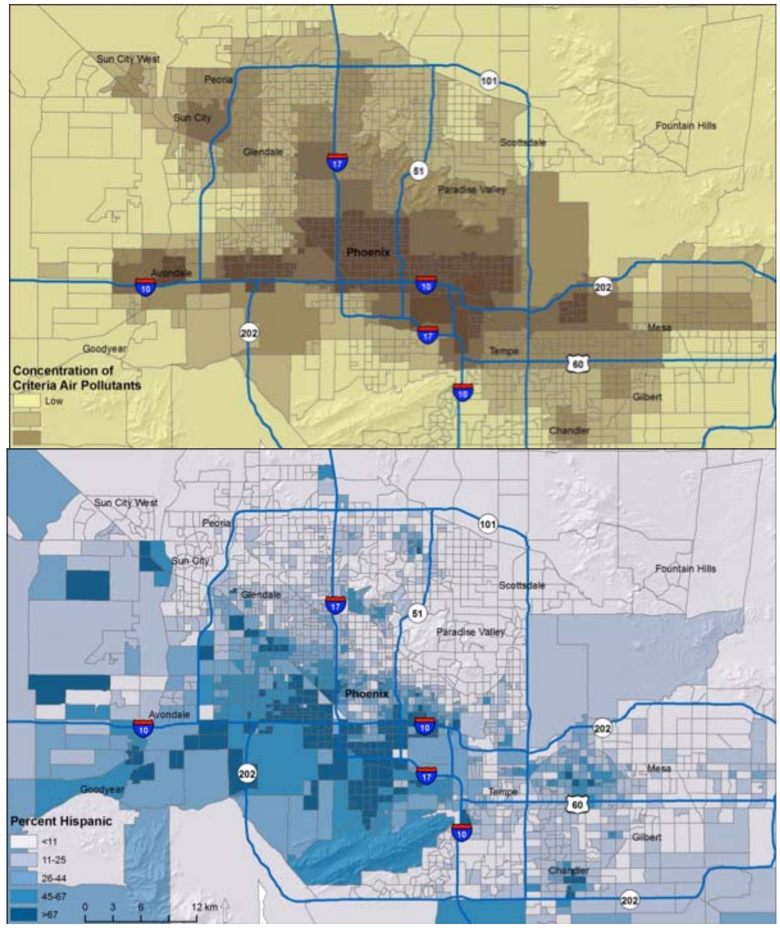

Figure 14. Spatial distributions of (top) criteria air pollutants and (b) percentage of the population that is in the Hispanic ethnic group. From Grineski et al. (2007).

implications. For example, we found distinct sociospatial inequalities in exposure to pollutants; neighborhoods of lower socioeconomic status, and including a higher proportion of renters and Latinos, generally experience higher levels of air pollution (Grineski et al. 2007; Fig. 14). Urban lead (Pb) distributions also are heterogeneous and higher in poorer neighborhoods. These differential impacts reflect historical patterns of development in Phoenix, with legacies of spatial segregation based on class, race, ethnicity, amenities, and disamenities that linger today (Bolin et al. 2005).

Human Control of Biodiversity (BIODIV)

Ecological approaches to studying human impacts on biodiversity have typically focused on habitat loss and disturbance brought about by human population agglomerations. Our studies have been unique in their focus on mechanisms accounting for changes in species diversity and community composition (Shochat et al. 2006b/). At the metro scale, land-use change and human choice and action have resulted in altered plant, bird, and arthropod communities. Urban plant diversity (influenced most by landscaping aesthetics and socioeconomics) is considerably lower and more even compared with native desert communities, (Hope et al. 2003, 2006; Walker et al. 2009; Fig. 15). For birds, community composition mirrors the variation in plant communities associated with landscaping aesthetics and socioeconomics. Irrigation drives ground-arthropod community patterns, with greater abundance and diversity in mesic and oasis (grass with a landscaped gravel border) landscapes (Cook and Faeth 2006; see Section III.A.2 for definition of landscape types). Arthropod species richness has declined over the last decade in desert remnant sites and xeric yards, possibly owing to landscape practices or isolation of these sites from colonist sources (outlying desert; Bang and Faeth *in prep.*).

CAP researchers have used experimental and synthetic approaches to determine how urbanization affects trophic dynamics. Our mechanistic, experimental studies of "giving-up density" (a surrogate for how long birds will persist at a foraging patch; Shochat et al. 2004, 2006a, 2006b, 2010) show that competition is active in the urban environment despite high-resource abundance, whereas predation is low. Elevated urban-habitat productivity and reduced temporal variability contributed to trophic systems that were radically different from their natural counterparts, with a shift to combined bottom-up and top-down control of trophic dynamics (Faeth et al. 2005). The question that remains is whether species loss occurs due to biotic interactions or differential vulnerability to stress. We do know that some urban birds differ from their desert counterparts in terms of physiological response to stressors (Fokidis et al. 2009; Deviche et al. *in review*; Fokidis and Deviche *in review*). Findings across biota in the CAP research area call into question the "field of dreams" hypothesis (that constructed landscapes meant to imitate the desert are functionally equivalent): trophic dynamics, richness, or species composition in desert-like residential landscapes and desert remnants are not analogous to the native desert.

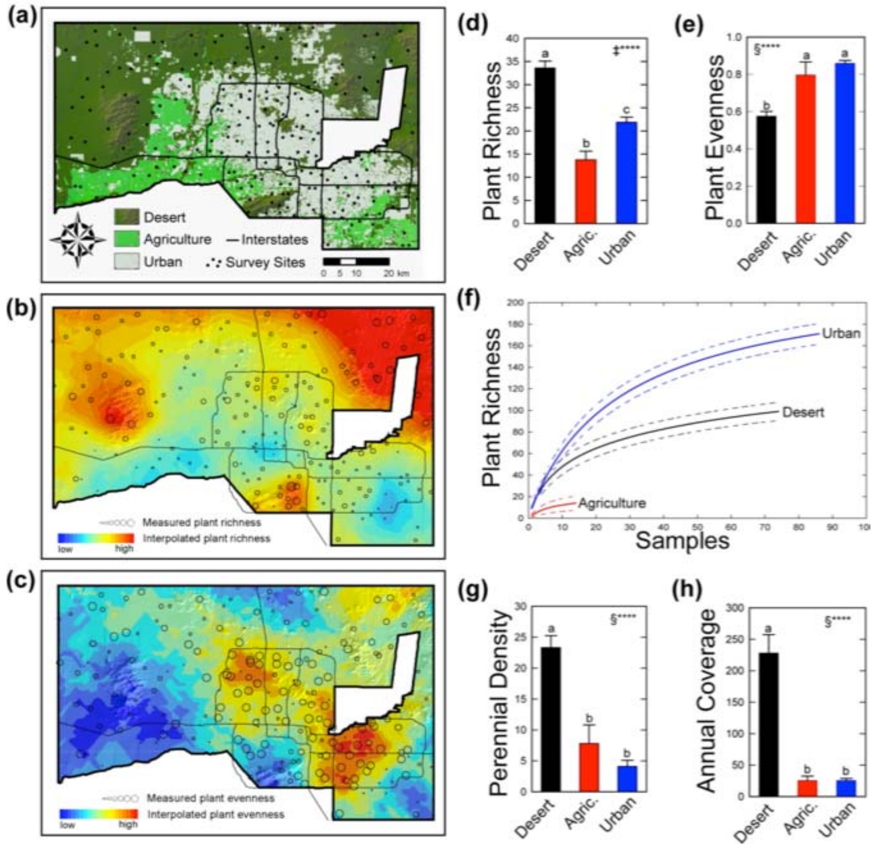

Figure. 15. Results from the 2005 Survey200 show strong variation in plant richness (b) and evenness (c) corresponding to coarse-scale land use (a) at the plot scale (d, e), a regionally higher species pool in the urban environment than in desert or agriculture (f) and much higher density of native perennial plants (g) and coverage of native annual plants (h) in desert than in agricultural or urban land uses.

Human responses to biota—the kinds and forms of vegetation, for example—depend upon on a complex set of preferences that we are beginning to unravel with our experimental landscapes work in a single neighborhood, coupled with social-survey data (e.g., Larson et al. 2009a). We found that residents preferred mesic and oasis landscapes over xeric and desert landscapes and that the longer they had lived in the Phoenix area the *less* they preferred arid landscapes. Oasis landscapes have emerged as a compromise, as residents reconcile desires for turf with concerns about water scarcity and environmental values (Yabiku et al. 2008; see Section III.A.2 for definition of landscape types).

Finally, resident satisfaction with the existing variety of birds in their neighborhoods was significantly correlated with actual bird diversity and with general neighborhood-satisfaction levels. Predominantly Hispanic and low-income neighborhoods in Phoenix had lower bird diversity (Kinzig et al. 2005), suggesting that the aesthetic cultural services associated with biodiversity are inequitably distributed in the region.

Model Development and Synthesis

Since CAP1, we have conceptualized the urban SES as a landscape of patches interacting at multiple scales, each with characteristic biophysical and social structure. This model underlies our biophysical and social survey designs and sees further development in the CAP3 proposal in the concept of “sustainable land architecture.” Even our mesoscale climate modeling is predicated on the idea that, to understand atmospheric dynamics, the heterogeneous land surfaces of urban areas must be included (Grossman-Clarke et al. 2008). Modeling research in CAP2 developed a version of the Patch Arid Land Simulator (PALS) for the Sonoran Desert (Shen et al. 2005) and used it to evaluate how changes in temperature, CO_2, N deposition, and rainfall would alter desert ecosystem productivity and soil properties (Shen et al. 2008). More recently, this model has been recoded to characterize the more urban patch types of this desert region: irrigated mesic yards, xeriscaped patches, and urban core areas with a high proportion of impervious surface. Once completed, this system of models will give us the ability to run scenarios for the landscape as a whole and as a function embedded individual patches.

We have produced several synthetic and review papers based upon CAP research (Grimm and Redman 2004: Faeth et al. 2005; Kaye et al. 2006; Shochat et al. 2006a; Grimm et al. 2008a, b). Using scenarios as well as visualization tools, synthesis will be a prominent feature of CAP3.

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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

Chow, Winston. Simulation of canopy-level UHI using a coupled urban canopy-mesoscale meteorological model: Evaluation using in-situ surface energy balance measurements (Ph.D., Geography, A. Brazel).

Hale, Rebecca. Urban ecohydryological landscapes: Design, disturbance, and institutional response (Ph.D., Biology, N. B. Grimm).

Hamilton, George Alex. Black carbon isotopic composition, concentration, and distribution in an urban/desert ecosystem (M.S., Chemistry and Biochemistry, H. Hartnett).

Hartz, Donna A. Human vulnerability and adaptation to heat. (Ph.D., Geography and Urban Planning, A. Brazel).

Hedquist, Brent. Micro-scale evaluation of the urban heat island in Phoenix, Arizona (Ph.D., Geography, A. Brazel).

Iwaniec, David. State change in urban systems (Ph.D., Sustainability, J. Wu).

Kim, Won Kyung. Understanding open spaces in arid cities (Ph.D., Geography, E. A. Wentz and S. W. Myint).

Lerman, Susannah. Residential landscapes and bird community structure: Understanding the patterns and processes. (Ph.D., Graduate Program in Organismic and Evolutionary Biology, University of Massachusetts, P. Warren).

Lund, Tracy. Major and trace element cycling in an arid-land stream (M.S., Geology, E. Shock).

Marusenko, Yevgeniy. Microbial degradation of non-point carbon deposition in urban soil (M.S., Biology, S. Hall).

Sweat, Ken. The use of lichens as biomonitors or heavy metal air pollution patterns in Arizona. (Ph.D., Plant Biology, T. H. Nash).

Taylor, Carissa. Local food in the Phoenix metropolitan area: Perceptions and heterogeneity of local food system stakeholders. (Ph.D., Sustainability, R. Aggarwal & H. Eakin)

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

Trujillo, Jolene. The historic agriculture and its effect on modern biogeochemical nutrient cycling (M.S., Biology, S. Hall).

Completed

2010

Bang, Christofer. The effects of urbanization on structure, diversity and trophic dynamics in arthropod communities (Ph.D., Biology, S. Faeth and J. Sabo).

Busse, Kendra. 2010. The effect of surface cover and vegetation on microclimates in Phoenix residential neighborhoods (M.S., Department of Applied and Biological Sciences, ASU-Polytechnic, C. A. Martin).

Cutts, Bethany B. 2010. Public knowledge of water resources as a product of multiple information providers. (Ph.D., Biology, A. Kinzig).

Fokidis, H. Bobby. Neuroendrocrine and nutrition-based mechanisms of adaptive plasticity underlying urbanization of native birds (Ph.D., Biology, P. Deviche).

Gade, Kris. Plant migration along freeways in and around an arid urban area: Phoenix, Arizona (Ph.D., Biology, A.P. Kinzig).

Larson, Elisabeth. Water and nitrogen in designed ecosystems: Biogeochemical and economic consequences (Ph.D., Biology, N. B. Grimm).

Zhuo, Xiaoding. 2010. Spatial distributions of toxic elements in urban desert soils: Sources, transport pathways, historical legacies, and environmental justice implications (Ph.D., Department of Chemistry and Biochemistry, E. Shock).

2009

Choi, Chi Chi. 2009. Comprehensive water, salt and energy flux modeling for urban systems (M.S., Civil, Environmental and Sustainable Engineering, P. Westerhoff).

Literral, Jennifer. 2009. Effects of urbanization on avian species diversity in the Phoenix, Arizona, USA metropolitan region: Patterns in vegetation remnants (M.S., Plant Biology, J. Wu).

Ontiveros Valencia, Aura V. 2009. Arbuscular mycorrhizal and dark septate endophytic fungi in urban desert preserves and surrounding Sonoran Desert. (M.S., Applied Biological Sciences, J. Stutz).

Ruddell, Darren. 2009. Scale and scientific inquiry: an investigation of theoretical, methodological, and practical applications (Ph.D., Geography, E. Wentz).

2008

Buyantuyev, Alex. 2008. Effects of urbanization on the landscape pattern and ecosystem function in the Phoenix metropolitan region: A multiple-scale study (Ph.D., Plant Biology, J. Wu).

Davies, Rachel. 2008. Human influence on nutrient cycling in Phoenix, AZ. (M.S.,Biology, S. Hall).
Neil, Kaesha. 2008. Effects of urbanization on flowering phenology in Phoenix, USA. (Ph.D., Plant Biology, J. Wu).
Walker, Jason. 2008. Socio-ecological effects of urban forest structure in Phoenix (Ph.D., Plant Biology, J. Briggs).

2007

Bigler, Wendy. 2007. Historical biocomplexity in irrigation agriculture. The Akimel O'Odham (Pima) and the Gila River, Arizona (Ph.D. ,Geography, R. Dorn).
Gonzales, Daniel. 2007. Dry deposition of speciated ambient fine particles measured using eddy correlation mass spectrometry (Ph.D., Chemical Engineering, J. Allen).
McLean, Brandon. 2007. Geochemical consequences of management on water resources in central Arizona, USA. (M.S., Geology, E. Shock).
Miller, James 2007. Local and regional climate change in the Mojave Desert, USA. (Ph.D., Geography, A. Brazel).
Zhang, Peng. 2007. Urban water supply, salt flux, and water use. (M.S., Civil and Environmental Engineering, J. Crittenden and P. Westerhoff).

2006

Bills, Robert. 2006. Effects of urbanization on community structure and functioning of arbuscular mycorrhizal fungi. (M.S., Plant Biology, J. Stutz).
Block, Jessica. 2006. 3-D Visualization for water resources planning and for Salt River paleo-geomorphology in central Arizona (M.S., Geology, J R. Arrowsmith).
Grineski, Sara. 2006. Social vulnerability, environmental inequality and childhood asthma in Phoenix, Arizona. (Ph.D., Sociology, B. Bolin).
Parker, John. 2006. Organizational collaborations and scientific integration: The case of ecology and the social sciences (Ph.D., Sociology, Ed Hackett).
Singer, Catherine. 2006. Effects of landscape surface mulches on desert landscape microclimates and responses of three Southwest desert plants to landscape surface mulches and drip irrigation. (M.S., Plant Biology, C. A. Martin).
Stiles, Arthur. 2006. Structure and distribution of Sonoran Desert plant communities in metropolitan Phoenix, Arizona. (Ph.D., Plant Biology, S. Scheiner).
White, Jacqueline. 2006. Resilience of the plant community and seedbank in an urbanized riparian corridor (Salt River Phoenix, Arizona) (M.S., Plant Biology, J. Stromberg).

2005

Collins, Timothy. 2005. The production of hazard vulnerability: The case of people, forests, and fire in Arizona's White Mountains. (Ph.D., Geography, K. McHugh).
Roach, W. John. 2005. How anthropogenic modifications influence the cycling of nitrogen in Indian Bend Wash (Ph.D., Biology, N. B. Grimm).

2004

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

Hartz, Donna. 2004. A case study of suburban development and microclimate variability in a desert urbanized environment (M.A., Geography, A. Brazel).

Jenerette, G. Darrel. 2004. Landscape complexity and ecosystem processes of the Phoenix region. (Ph.D., Plant Biology, J. Wu).

Marussich, Wendy. 2004. The costs and benefits of myrmecochory between ants and datura in the Sonoran Desert (Ph.D., Biology, S. Faeth).

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

VI. EDUCATION AND OUTREACH

K-12 Education Program

CAP reaches out to the K-12 community through our award-winning Ecology Explorers program, which engages teachers, students, and community organizations throughout the Phoenix metro area. Ecology Explorers aims to:

- improve scientific literacy by exposing students and teachers to university research;
- enhance teachers' capabilities to design lessons and activities that use scientific-inquiry methods and that are aligned with Arizona academic standards;
- encourage interest in science amongst school-age children and their parents;
- provide access to (and promote the use of) CAP research in K-12 classrooms; and
- spark collaboration between CAP researchers and the K-12 community.

To reach these objectives, we have worked with teachers to implement lessons and research protocols involving ground arthropods, bruchid beetle/palo verde interactions, birds, and urban and desert plant communities. This knowledge exchange is the basis for the Ecology Explorers website http://ecologyexplorers.asu.edu, first developed in 1998, which includes an online-entry feature for schoolyard data collected with CAP LTER protocols.

Over 200 teachers have participated in our workshops and internships and, through these teachers and direct classroom presentations, we have connected with thousands of students. Evaluations have shown that teachers incorporate some aspect of ecological research into their curriculum after participating in our programs (Banks et al. 2005), and research has underlined the value of using qualitative conceptual models in teacher education and the K-12 classroom for developing ecological understanding (Dresner and Elser 2009).

Key achievements of the program during CAP2 include:

- Training of Phoenix area high school science teachers to conduct authentic field research and use qualitative modeling to broaden their understanding of complexity, diversity, and ecology as a science through participation in the cross-LTER site Teaching Ecological Complexity grant (http://teachers.ecoplexity.org/home).
- Development of closer collaborations with other environmental education organizations in the region, such as the Chandler Environmental Education Center and the Gilbert Riparian Institute.
- Growth of partnerships with school districts to provide Ecology Explorers workshops for teachers that address specific learning goals.
- Receipt of the 2006 Arizona State University President's Medal for Social Embededness for the Service at Salado service learning program that ran from 2005-2008.
- Development of learning modules on the urban heat island in collaboration with a NSF ITEST grant (http://k12engineering.asu.edu).
- Continued success in targeting schools and districts with minority populations and a large percentage of students qualifying for the free and reduced cost lunch program.
- New partnership with Navajo Elementary School, which includes installation of a WeatherBug© weather station on their campus and the development of activities to incorporate weather studies into their curriculum design.
- Redesign of Ecology Explorers website to improve teacher and student access to resources, activities, and curriculum.

Undergraduate and Graduate Training

Undergraduate and graduate student research, education, and mentoring are fundamental to CAP's mission. CAP provides an excellent platform for student research, which has been instrumental in forwarding our socioecological investigations. Key indicators of this success include:

- Over 60 theses and dissertations written since 1997.
- 59 papers published with students as first authors since 2004; 94 papers in total (including in review and in press) with students as co-authors.
- Student authorship of papers in a wide range of top-ranked journals, including *Frontiers in Ecology and Environment, BioScience*, and *Social Science Quarterly*.
- 36 graduate research projects directly funded through CAP graduate grants since 2004.
- 34 students funded as Research Assistants to faculty research projects since 2004.
- 17 undergraduate research projects funded since 2004 through the Research Experience for Undergraduates program on topics ranging from work on summer monsoons and carbon cycling to vegetation density and crime in urban parks.
- Receipt of two CAP-leveraged NSF grants to establish an Integrative Graduate Education and Research Training (IGERT) in Urban Ecology.
- Growth of the newly-established Graduates in Integrative Society and Environment (GISER) group, which will to continue graduate student-driven interdisciplinary research related to society and environment. CAP is playing a role in funding this student research.

Community Outreach

Community outreach in CAP2 has been primarily centered around ecological education activities through the Ecology Explorers program. Each year, Ecology Explorers staff reaches thousands of children and adults through various family environmental education events. In CAP2, Ecology Explorers developed a new, interactive display unit that uses pictures, text, and graphs to convey key information about the urban heat island, native birds, plants, and arthropods in the CAP study area, drawing on data from CAP research. CAP scientists also give presentations to community groups that wish to learn more about urban ecology in the Phoenix region.

Dissemination of Research Results

Since 2004 CAP2 participants have produced 230 journal articles (181 published, 17 in press, 32 in review) and 66 book chapters and books (51 published, 11 in press, 4 in review). In addition, research results are routinely presented at meetings and conferences in a diverse array of fields. Media attention on CAP LTER projects has included articles in *High Country News*, *Scientific American* online, *The Arizona Republic*, and *The San Diego Union-Tribune*.

The CAP website, http://caplter.asu.edu/, was redesigned in early 2010 to present a stronger visual presence for the project on the web and to highlight the research accomplishments of the project. It receives around 1000 hits per month with a high percentage of unique visitors. Research content on the website is regularly pushed out to 78 mostly institutional Twitter followers @CAPLTER. The Twitter content also includes links to other information on environment in the Phoenix area, urban ecology, and CAP research publications.

Selected List of CAP Visitors 2004-2010

Marina Alberti. University of Washington

Maria Baier, Arizona State Land Commissioner

Sam Foster, USDA Forest Service, Rocky Mountain Research Station

James Gosz, University of Idaho

Peter Groffman, Institute of Ecosystem Studies

Morgan Grove, USDA Forest Service, Northern Research Station

Philippe Jamet, Embassy of France in the United States

Eun-Shik Kim, Kookmin University, South Korea

Kai Lee, Williams College

Elinor Ostrom, Indiana University and Arizona State University

Johan Pauw, South African Environmental Observation Network

Stephanie Pincetl, University of California, Los Angeles

Osvaldo Sala, Brown University

Mark Stapp, Pyramid Developers

Brent Steel, Oregon State University

Ernst Ulrich von Weizsaecker, University of California, Santa Barbara

Jeff Williamson, Phoenix Zoo

Jess Zimmerman, Institute for Tropical Ecosystem Studies

Ouyang Zhiyun, Chinese Academy of Sciences

The highlight of each year is the CAP LTER **Annual Poster Symposium**, held in January. 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). Monthly **All Scientists Meetings** (ASMs) attracted between 40 and 100 participants, including community partners, and featured scientific presentations by visitors or discussions of project results. The sidebar includes a selected list of visitors to CAP LTER, including speakers at the Annual Poster Symposium and the All Scientists Meetings.

Cross-Site and Network Activities

Comparative studies of cities as socioecological systems are largely absent from the literature, and we see tremendous advantages in collaborating with other LTER sites in this realm (e.g., Grimm et al. 2008b). In particular, we seek to understand how patterns, processes, and mechanisms found in our study area may contrast with other urban areas and examine what the commonalities and differences may reveal about the universal nature of urban socioecological system.

Key cross-site initiatives under CAP2 are:

- **Land fragmentation and urbanization** research at three Southwestern sites (CAP, JRN, and SEV) and two grassland sites (SGS and KNZ) associated respectively with the Phoenix, Las Cruces, Albuquerque, Fort Collins and Manhattan, Kansas urban areas. Work thus far has characterized drivers of land fragmentation with the five urban areas (Zhang et al. in review; York et al. in press).
- Work on a comparative **analysis of the long-term dynamics of environmental justice** in Phoenix and Baltimore. This research will be published in an upcoming volume (Boone and Fragkias editors, Springer Press) that examines linkages between urban ecology, environmental justice, and global environmental change.
- Ongoing **comparative research on avian community ecology** in the Baltimore and Phoenix metropolitan areas (Shochat et al. 2010).
- **Residential landscapes research** with BES, PIE, and FCE that explores the relationships among the drivers of residential-landscape decisions at multiple scales, the diversity of household-management practices, and their impacts on ecological properties and processes

associated with ecosystem services. This research, building on CAP residential landscape studies (K. Larson et al. 2008, in review), employs a common, parcel-scale, classification scheme coupled with detailed measurements of ecosystem processes and human attitudes and actions.

- **Comparative urban climate research** between the Phoenix and Baltimore areas (Brazel and Heisler 2009; Brazel et al. 2000)
- Development of a primer on **key social science theories for LTER research**. This initiative, headed by David Foster of Harvard Forest, is in progress and involves two CAP scientists, Boone and Childers.
- **Maps and Locals** (MALS; www.lter.uaf.edu/bnz_MALS.cfm) initiative across 19 LTER sites and 3 international sites. This project's goal is to understand drivers and indicators of land-use change and identify socio-economic and ecological tipping points. CAP has already contributed imagery to this initiative and will use its rich datasets to illuminate land-change processes at the local scale.
- **ULTRA-Ex: Land and water-use decision-making and ecosystem services along a southwestern socio-ecological gradient**. This initiative involves scientists at CAP, SEV and JRN and will commence in fall 2010.
- **Scenarios of Land Change**, a LTER Network-wide initiative. Grimm and Redman have been part of the team that planned the network-level scenarios of land change work during workshops at Science Council meetings, the LTER ASM, and at HVR.
- At the network level, CAP scientists are avid participants in the LTER All Scientists Meetings and continue to be active in the LTER social science community through initiatives that seek greater integration of social science research into ecological investigations. CAP also is contributing to the NEON program through identifying a peri-urban location for a relocatable tower. Lead PI Childers is on the NEON Board of Directors.

Other Collaborations and Partnerships

The **Global Institute of Sustainability** (**GIOS**) is the home base of CAP LTER, as well as the Decision Center for a Desert City, the Urban Ecology IGERT, the Decision Theater and many other programs. GIOS' outreach efforts engage academic, business, and governmental groups in dialogues about pressing environmental issues affecting our rapidly growing desert metropolis. In October 2006, ASU launched the new **School of Sustainability** (an entity under GIOS) as the first academic school in the country to be focused upon sustainability science and studies. CAP LTER retains strong linkages to the School through its faculty and is involving its graduate and undergraduate students in CAP research.

Since 1997, CAP has formed partnerships with governments and institutions at the municipal, state, and federal levels to conduct research of mutual benefit and to deliver education programs. These partners are listed in the sidebar.

Selected Partners and Collaborators

City of Tempe

City of Scottsdale

City of Phoenix

US Geological Survey

Arizona Department of Water Resources

Arizona Department of Environmental Quality

Arizona State Land Department

Arizona Department of Game and Fish

Maricopa Association of Governments

Flood Control District of Maricopa County

Salt River Project

Desert Botanical Garden

Chandler Environmental Education Center

Arizona Science Center

Boys Hope Girls Hope

Deer Valley High School District

Gilbert Public Schools

Maricopa Community Colleges

Tonto National Forest

Arizona Foundation for Resource Education

Maricopa Parks and Recreation Department

Kyrene School District

Mesa Public Schools

Peoria Unified School District

Phoenix Elementary School District

The Phoenix Zoo

Scottsdale Unified School District

VII. CONTRIBUTIONS

Contributions within Discipline

- For most of ecology's history as a discipline, the focus of study was on pristine, wildland sites. Since 1997, CAP LTER has played an important role in forwarding the study of **urban ecosystems** and in developing the discipline of **urban ecology** (Grimm et al. 2008, 2000; Grimm and Redman 2004; Warren et al. in review).
- CAP has been at the forefront of a movement to conduct **socioecological investigations** that use social science and ecological methods to understand cities as well as to create socioecological theories to describe how urban areas function (Redman et al. 2004; Haberl et al. 2006; Costanza et al. 2007; Liu et al. 2007a, b; Grimm et al. 2008b).

Contributions to Other Disciplines

- CAP LTER is a **multidisciplinary endeavor** and involves scientists from a range of disciplines in examining a common set of research problems. While multidisciplinary projects have their challenges (Baker 2006), they can lead to important syntheses of data and information that would otherwise be impossible under a single disciplinary approach. As a result, contributions often extend beyond disciplinary boundaries.
- Research on **urban bird dynamics** uses a mechanistic approach to understanding avian communities within urban settings. Such an approach is rare in community ecology, and CAP scientists are at the forefront of debates on how to achieve a better balance between observational and mechanistic research in urban ecology.
- **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. These data provide a framework for understanding the spatial picture across the CAP region and have been used extensively by a wide variety of project researchers (both faculty and students) in fields ranging from avian community ecology to soil biogeochemistry. To date, 13 papers have been prepared using these data.
- Collaborations between statisticians and biological scientists have led to fruitful collaborations that use new techniques to analyze CAP data. A recent example of this was the analysis of **Survey 200** data, using hierarchical Bayesian modeling techniques. This endeavor was the first work of its kind to use such techniques and kriging strategies to study multivariate soil nutrient and carbon concentrations.
- **PASS** 2006 has successfully launched transdisciplinary collaborations across a number of important environmental issues in a rapidly urbanizing region. There is not a single dominant disciplinary perspective in PASS, but it is contributing to sociology, geography, economics, ecology, anthropology, and meteorology in unique and important ways. The longitudinal design of the survey is in keeping with tradition in the field of sociology, which values research on long-term trends in social attitudes and behaviors. The most highly-regarded social surveys have continued over a period of 40 or 50 years. PASS researchers are pioneering new methods of survey design in order to allow spatial analyses of people's attitudes and behavior in relation to fine-scale environmental conditions in neighborhoods.

- Findings from the **NDV Experiment** have applications in fields such as architecture and landscape planning. Researchers are working toward an improved understanding of the effect of different landscaping types on power and water usage - both from the biophysical effects of the landscapes themselves, and on the behavior 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 affect behavior, which ultimately affect biophysical landscape processes.
- Work on **residential lawns** contributes to integrated social-ecological approaches through development of multidisciplinary conceptual framework and mixed methods involving coupled social-field surveys (most of past research is social or ecological in orientation). Whereas many past studies have focused on experimental plots (e.g., in lawn/turfgrass research) as well as broader regional-scale land use/cover change analyses, this research is an integrated field-based study of residential landscapes at the parcel scale. Furthermore, the study of residential lawns includes multidimensional analyses of different types of values (general life values, ecological orientations, and landscape-specific priorities) in relation to multiple human ecological behaviors in residential landscapes (land cover/structure and associated management practices), whereas many studies have narrowly examined singular or relatively few values and behaviors.
- CAP research on the **urban heat island** (UHI) has contributed to knowledge about the spatial variation in the UHI across metropolitan areas and the environmental justice implications of this distribution. Using remote sensing data, CAP researchers have found that the distribution of urban heat islands in the Phoenix metropolitan area is spatially variable, mirroring the physical variability of soils, extents of pavement, housing density, and vegetation. Their research has shown that extreme temperatures are distributed unevenly among neighborhoods with the most affected neighborhoods characterized by already vulnerable minority, low-income, and elderly populations.
- Work on modeling land use change and ecosystem responses and landscape ecology in general has made noticeable contributions to these fields in the US and around the world. For example, the landscape gradient approach to urban pattern analysis has been applied in several studies in China and Europe. Work on urban modeling and land use analysis contributed significantly to the special issue of the journal, *Urban Ecosystems* (Musacchio and Wu 2004) and a book on scaling and uncertainty analysis in ecology (Wu et al. 2006). The **Hierarchical Patch Dynamics** framework has been used for urban ecology and landscape analysis in several other countries (including, China, Canada, Australia, and Europe).
- CAP scientists have used the special characteristics of urban food webs (**trophic dynamics**) to test long-standing ecological theories about organismal interactions, biodiversity, and the assembly of communities. In particular, diversity patterns of birds and some arthropods in urban ecosystems suggest that exotic and invasive species associated with human settlements (e.g. pigeons and grackles) often outcompete native species that could otherwise inhabit cities. In Phoenix, the diversity of plants is actually higher in the city compared with the surrounding Sonoran desert ecosystems because people have introduced many native species to create the desert "oasis city." Long-term data sets have allowed CAP researchers to investigate these changes over time as the

Phoenix metropolitan area has grown.

Contributions to Resources for Research and Education

- CAP LTER's setting within a university enhances the ability to conduct, communicate, and synthesize research activities. Faculty members have expanded their courses to include a consideration of urban ecology and, in some cases, have designed new courses to accommodate CAP LTER interests. The multi-disciplinary courses taught in the IGERT in Urban Ecology program are good examples of integrative science in action. In fall 2008, for instance, CAP scientists Sharon Hall and Kelli Larson convened an IGERT workshop course on residential landscapes, which was centered on an ongoing CAP research initiative.
- A spring 2009 course, "From yardstick to gyroscope: Interdisciplinary methods for the long-term study of social-ecological systems," involved students from four universities (ASU, University of Georgia, Florida International University, and University of Vermont) in learning about socioecological research in the LTER Network.
- CAP research provides a learning laboratory for undergraduate and graduate students at ASU. For example, CAP scientist Hilairy Hartnett's research on dissolved organic carbon in Tempe Town Lake, is a unique "backyard" research project for her laboratory and classroom students. CAP scientist John Sabo has used project resources to teach undergraduate students in his ecology course about controls of food chain lengths in urban desert environments through experimentation with brittlebush (*Encelia farinosa*) at CAP's experimental space in the Desert Botanical Gardens.
- The Global Institute of Sustainability, the administrative home for the CAP LTER, houses the Informatics Lab and provides support, management staff, 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.
- New initiatives to create multi-scalar land cover and land use classification maps provide important resources for future CAP research. Efforts to standardize classification schemes among LTER sites provide scientists with necessary data for comparative research.
- 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 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 cross disciplinary projects, and contributing to the new and growing field of urban ecology. Our project is also committed to engaging pre-college and undergraduate students, and K-12 teachers, community organizations, governmental agencies, industry, and the general public in our multilayered investigation.

- Since the inception of CAP LTER, close to 30 postdoctoral associates have taken leadership roles in research and outreach activities. The project currently supports four post-doctoral associates, three full-time on CAP LTER and one shared with DCDC. The individuals 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.
- Five graduate students a semester and during the summer months are involved in CAP LTER, 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 a total of 37 grants have been awarded. The awardees typically present their research findings at a meeting of scientists in the fall and present additional results at the annual poster symposium.
- 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.
- Students involved in CAP LTER are encouraged to present their research results at various local, national, and international meetings. Students have been presenters in approximately 42% of presentations given by CAP scientists at national and international meetings since 2004. They comprise around 45% of the presenters at CAP poster symposia.
- As active participants in CAP research, students are involved in publishing research results. During the current grant period, a total of 94 papers and book chapters have been co-authored by students (including works in press and review) and on 59 of these, the student was the first author. These papers have appeared in a wide range of journals, including *Ecology*, *BioScience*, *Social Science Quarterly*, the *International Journal of Remote Sensing*, *Frontiers in Ecology and the Environment*, and *Human Organization*.
- Since 2004, CAP LTER faculty members, postdoctoral associates, and senior graduate students have mentored 17 summer and academic year REU students. Many other REUs have become involved in CAP research through other, CAP-leveraged projects.

Undergraduates from ASU who are working on CAP LTER projects during the academic year can be part of the Community of Undergraduate Scholars, a program sponsored by the Global Institute for Sustainability and the Barrett Honors College. Other undergraduate students have benefited by participating in data collection for the PASS, ground arthropod and bird studies, collection and curation activities, and courses that relate to the CAP LTER. Students have also incorporated project research into undergraduate honors and senior theses.

- Outside of the CAP-funded REU experience, CAP scientists are involving undergraduates in their research. One excellent example of this is Chad Johnson, who has involved numerous undergraduates into his research on black widow spider behavior. Presently, his students are first authors on several papers in review and in preparation for scholarly journals.
- Monthly All Scientists Meetings (ASMs) 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.
- 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 postdoctoral associates 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 Global Institute of 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. Many results from CAP LTER projects have public policy implications, and working through other projects within GIOS, such as the Decision Center for a Desert City (DCDC), and our partners, we are able to convey these results to decision makers.

- 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. We believe that the publication and communication of our research results will enhance policy-makers' ability to address water-related environmental problems in the Southwest. CAP scientists active with DCDC have been working to communicate these results. In addition, CAP will continue to be active in initiatives forwarded by GIOS and the Sustainable Cities Network, such as those involving water managers in Arizona, which gives the project access to important stakeholder groups.

- Divergence in mental models between the public and decision makers can be problematic and lead to controversy over risk management priorities. Such divergences can also represent areas where dialogue between experts and lay groups could be fruitful. Research on **ethnohydrology** points to areas where public education and outreach can play a role in educating those concerned about their water quality to: i) reduce unnecessary concern for quality and safety surrounding tap water, and ii) cultivate consensus about how communities can communicate with authorities regarding improvements to local municipal water. To facilitate such dialogue, CAP scientist and water resources engineer, Paul Westerhoff, has begun to discuss and share research findings with Phoenix water planners on an informal basis.
- The **PASS** is a vehicle for increasing knowledge of how residents shape and respond to the local environment, which is a necessary step in devising a more sustainable city. 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.
- Research on the **urban heat island**, including work on populations vulnerable to excessive heat, been shared with policymakers and practitioners through the City of Phoenix’s Urban Heat Island Task Force and its Tree and Shade Task Force. These budding partnerships between practitioners and scientists will enhance efforts toward ameliorating the heat island as well as possibly influence new research directions within CAP LTER.
- **NDV** research seeks to discover whether people's landscape preferences can be changed, or if they evolve over time. Do people prefer mesic to more water-saving designs simply because they are unfamiliar with xeric and native designs? Understanding the mechanisms behind landscape preferences is important for urban planning as municipalities seek to promote water-saving landscapes. As well, new research on ecosystem services will explore tradeoffs principally between water and energy in landscapes. Researchers anticipate that this will allow them to determine if any landscape is optimal for water and energy conservation.
- Research on **environmental risk and justice** is shifting from a focus on analyzing the distribution of disamenities and amenities in relation to population groups to a combined analysis of these patterns and the processes that create them as well as equity in public decision making. There has been an increased emphasis on vulnerability analysis in environmental justice work in order to mitigate future environmental inequities. This provides considerable scope for engaging policymakers in research.
- Understanding **how urban ecosystems function** provides knowledge to urban planners who design urban systems for public benefit. CAP research has found both intended and unintended ecosystem services associated with highly engineered aquatic systems in the urban environment (e.g., systems for water delivery, storm water removal, and

wastewater processing). Parks along a flood "greenway," such as Indian Bend Wash in Scottsdale, Arizona, are an excellent example. In addition to their obvious recreational value and capacity to absorb or convey floods, these parks are also efficient at removing nutrients and contaminants from floodwater. Retention basins, established for flood management, double as recreational spaces and nutrient removal systems. Other engineered aquatic ecosystems, however, do not provide benefits beyond those for which they were originally designed (e.g. concrete stormwater spillways). Awareness of the potential benefits of ecosystem functions increases the potential for urban planners and policymakers to design systems that optimize the ecosystem services delivered to the public.

VIII. CAP LTER Products

Journal Articles

In Press

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APPENDIX A
2004-2010 CAP LTER PARTICIPANTS

	Duration of Involvement
Principal Investigator	
Nancy Grimm, Life Sciences	1997-2010
Daniel Childers, Sustainability	2010-present
Co-Director	
Charles Redman, Sustainability	1997-present
Co-Principal Investigators	
Rimjhim Aggarwal, Sustainability	2009-present
John Anderies, Sustainability; Human Evolution and Social Change	2004-present
Ramon Arrowsmith, Earth and Space Exploration	1997-present
George Basile, Sustainability	2009-present
Bob Bolin, Human Evolution and Social Change	1999-present
Christopher Boone, Sustainability; Human Evolution and Social Change	2009-present
Anthony Brazel, Geographical Sciences and Urban Planning	1997-present
John Briggs, Life Sciences	1999-2008
Daniel Childers, Sustainability	2009-present
Pierre Deviche, Life Sciences	2009-present
Stevan Earl, Sustainability	2009-present
Monica Elser, Sustainability	1998-present
Stanley Faeth, Life Sciences	1997-2008
Matthew Fraser, Sustainability	2009-present
Corinna Gries, Sustainability	2000-present
Susanne Grossman-Clarke, Sustainability	2004-present
Sharon Hall, Life Sciences	2005-present
Sharon Harlan, Human Evolution and Social Change	1999-present
Hilairy Hartnett, Earth and Space Exploration; Chemistry & Biochem.	2009-present
Diane Hope, Sustainability	1997-2006
J. Chadwich Johnson, Mathematics and Natural Sciences	2009-present
Jason Kaye, Life Sciences	2002-2005
Ann Kinzig, Life Sciences	1999-present
Lauren Kuby, Sustainability	1998-2009
Kelli Larson, Sustainability; Geographical Sciences and Urban Planning	2005-present
Ananda Majumdar, Mathematics and Statistical Sciences	2009-present
Chris Martin, Applied Sciences and Mathematics	1997-present

Peter McCartney, Sustainability	1997-2006
Soe Myint, Geographical Sciences and Urban Planning	2009-present
Thomas Nash, Life Sciences	1997-present
Marcia Nation, Sustainability	2009-present
Jordan Peccia, Engineering	1997-2005
John Sabo, Life Sciences	2009-present
Brenda Shears, Sustainability	1997-2009
Everett Shock, Earth and Space Exploration; Chemistry & Biochem.	2009-present
Kerry Smith, Business	2009-present
Jean Stutz, Applied Sciences and Mathematics	1998-present
Billie Turner, Geographical Sciences and Urban Planning	2009-present
Arnim Weik, Sustainability	2009-present
Elizabeth Wentz, Geographical Sciences and Urban Planning	2004-2009
Paul Westerhoff, Engineering	2004-present
Amber Wutich, Human Evolution and Social Change	2009-present
Jianguo Wu, Life Sciences	1997-present
Scott Yabiku, School of Social and Family Dynamics	2009-present
Abigail York, Human Evolution and Social Change	2009-present
Senior Personnel: Managers	
Stevan Earl, Site Manager	2006-present
Monica Elser, Education Manager	1998-present
Corinna Gries, Information Manager	2000-2009
Diane Hope, Field Project Manager	1997-2006
Lauren Kuby, Communications Manager	1997-present
Peter McCartney, Information Manager	1997-2006
Marcia Nation, Project Manager	2006-present
Brenda Shears, Assistant Dir., GIOS	1997-present
Philip Tarrant, Information Manager	2010-present
Linda Williams, Finance Manager	1997-present
Senior Personnel: Scientists	
Braden R. Allenby, Engineering	2004-present
Ariel D. Anbar, Earth and Space Exploration	2004-present
James R. Anderson, Engineering	2001-present
Lawrence A. Baker, Water Resources Center, U of Minn.	1997-present
Heather Bateman, Applied Sciences and Mathematics	2009-present
Alexandra Brewis, Human Evolution and Social Change	2007-present
Megha Budruk, Community Resources	2006-present
David Casagrande, Sociology and Anthropology, W. Ill. U.	2003-present
Phillip Christensen, Mars Space Flight Facility	1997-present

Elizabeth A. Corley, Public Affairs	2004-present
James Collins, Life Sciences	2004-2005
William Cook, Biological Sciences, St. Cloud State U.	2004-present
John C. Crittenden, Engineering	2004-present
James J. Elser, Life Sciences	1997-present
Ananias A. Escalante, Life Sciences	2005-present
Stanley Faeth, Biology, U. of North Carolina, Greensboro	1997-present
Joseph Feller, Law	2004-present
H.J.S. Fernando, Engineering	1997-present
Jonathan Fink, Sustainability	2004-present
Stuart Fisher, Life Sciences	1997-2008
Janet Franklin, Geographical Sciences and Urban Planning; Life Sciences	2009-present
Patricia Gober, Geographical Sciences and Urban Planning	1997-present
Subhrajit Guhathakurta, Geographical Sciences and Urban Planning	2004-present
Edward J. Hackett, Human Evolution and Social Change	1997-2006
Nora M. Haenn, Human Evolution and Social Change	2004-present
Randel Hanson, Justice & Social Inquiry	2004-present
Pamela Hunter, Institute for Social Science Research	2005-2006
Jana Hutchins, Institute for Social Science Research	1997-present
Marcus A. Janssen, Human Evolution and Social Change	2005-present
Darrel Jenerette, Plant Biology, U. Calif-Riverside	2010-present
James Johnson, Integrated Natl. Sciences	2006-present
Paul C. Johnson, Engineering	1997-present
Eric Keys, Geographical Sciences	2004-2006
Andrew Kirby, Social/Behavioral Science	1997-present
Jeffrey M. Klopatek, Life Sciences	1997-present
Jennie J. Kronenfeld, Social and Family Dynamics	2004-present
Michael Kuby, Geographical Sciences and Urban Planning	2004-present
Leslie Landrum, Life Sciences	1998-present
Tim Lant, Decision Theater	2008-present
Kathleen Lohse, Natural Resources, U of Arizona	2005-present
Nancy E. McIntyre, Bio. Sciences, Texas Tech	1997-present
Melissa McHale, Biology, North Carolina State	2008-present
Geoffrey Morse, Integrated Natl. Science	2006-present
Laura R. Musacchio, Landscape Arch., U of Minn.	1999-present
Margaret C. Nelson, Human Evolution and Social Change	1998-present
David L. Pearson, Life Sciences	1997-present
K. David Pijawka, Geographical Sciences and Urban Planning	1997-present
Benjamin Ruddell, Engineering	2009-present
Mark Schmeeckle, Geographical Sciences and Urban Planning	2008-present
Milton Sommerfeld, Life Sciences	1997-present

Katherine Spielmann, Sustainability; Human Evolution & Social Change	2009-present
Ryan Sponseller, Biological Sciences, U of Alabama	2006-present
Juliet C. Stromberg, Life Sciences	1997-present
Emily Talen, Geographical Sciences and Urban Planning	2009-present
Sander van der Leeuw, Human Evolution and Social Change	2004-present
Paige S. Warren, Natl. Res. Con., U of Mass-Amherst	2004-present
David White, Community Resources	2005-present
Joseph A. Zehnder, Geographical Sciences	2004-2007
Post-Doctoral Research Fellows	
David Casagrande, Global Institute of Sustainability	2004-2005
William Cook, Global Institute of Sustainability	2004-2005
David Lewis, Global Institute of Sustainability	2004-2005
Jose Lobo, Global Institute of Sustainability	2005-2007
Kathleen Lohse, Global Institute of Sustainability	2005-2006
Louis Machabee, Global Institute of Sustainability	2002-2005
Melissa McHale, Global Institute of Sustainability	2007-2008
Maik Netzband, Global Institute of Sustainability	2004-2005
Darren Ruddell, Global Institute of Sustainability	2009-present
Eyal Shochat, Global Institute of Sustainability	2006-present
Milan Shrestha, Global Institute of Sustainability	2009-present
Chona Sister, Global Institute of Sustainability	2007-present
Ryan Sponseller, School of Life Sciences	2006-2007
Laura Turnbull, Global Institute of Sustainability	2009-present
Amber Wutich, Global Institute of Sustainability	2006-2007
Lin Ye, Global Institute of Sustainability	2009
Chi Zhang, Global Institute of Sustainability	2009-present
Research Technical Personnel	
Stevan Blackwell, Research technician, CAP LTER	2010
M. Amy DiIorio, Research technician, CAP LTER	2001-2005
Christine Giroux Dillon, Research technician, CAP LTER	2010
Laura E. Dugan, Research technician, CAP LTER	2005-2006
Amanda Kate Elrod, Research technician, CAP LTER	2009-present
Roy E. Erickson, Research specialist, CAP LTER	2000-present
Martin J. Feldner, Research technician, CAP LTER	2005
Steven W. Higgins, Research lab aide, CAP LTER	2004
Michael Holland, Research technician, CAP LTER	2008-present
Jill E. Jones, Research lab aide, CAP LTER	2004-2005
Roy M. Jones, Research lab aide, CAP LTER	2004-2005
Maya Kapoor, Research technician, CAP LTER	2010

Hooi Hong Khor, Institute for Social Science Research	2006
Cathy D. Kochert, CAP LTER lab manager	1999-present
Karen Lafrance, Research lab aide, CAP LTER	2006-present
Erin Manton, Research technician, CAP LTER	2008-2009
Heather Matthies, Research technician, CAP LTER	2010
David Morin, Research technician, CAP LTER	2010
Emily Morris, Research technician, CAP LTER	2008-present
Nicholas Pacini, Research technician, CAP LTER	2010
Shalini Prasad, Graphic designer, Global Institute of Sustainability	2005
Phil Puleo, Institute for Social Science Research	2006
Suzanne D. Rester, Research lab aide, CAP LTER	2005-2006
Laura Riley, Research lab aide, CAP LTER	2006-2008
Janaina Scannel, Institute for Social Science Research	2006
James Smith, Research lab aide, CAP LTER	2008
Quincy Stewart, Research technician, CAP LTER	2005-present
Valerie Steen, Research technician, CAP LTER	2005-2006
Diana Stuart, Research technician, CAP LTER	2000-2005
Maggie S. Tseng, Research technician, CAP LTER	1997-present
Katrina Wells, Institute for Social Science Research	2006
Sean A. Whitcomb, Research technician, CAP LTER	2005
Kymberly C. Wilson, Research technician, CAP LTER	2006-2007
Informatics Lab	
Raul Aquilar, Global Institute of Sustainability	2006-present
Ed Gilbert, Global Institute of Sustainability	2002-present
Corinna Gries, Global Institute of Sustainability	2000-2009
Peter McCartney, Global Institute of Sustainability	1997-2006
Wayne Porter, Global Institute of Sustainability	2000-2009
Philip Tarrant, Global Institute of Sustainability	2010-present
Cindy Zisner, Global Institute of Sustainability	1997-present
Public Outreach/Education Personnel	
Monica Elser, Global Institute of Sustainability	1998-present
Lauren Kuby, Global Institute of Sustainability	1998-present
Kathryn Kyle, Global Institute of Sustainability	1997-present
Maggie McGraw, Global Institute of Sustainability	2007-present
Tina Salata, Global Institute of Sustainability	2006-2008
Charlene Saltz, Global Institute of Sustainability	2000-2006
Research Support Personnel	
Bryan Barker, Global Institute of Sustainability	2009-present

Sara Eeds, Global Institute of Sustainability	2008-present
Tamlin Engle, Global Institute of Sustainability	2005-2009
J. Nikol Grant, Global Institute of Sustainability	2001-present
Karen Gronberg, Global Institute of Sustainability	2005-2010
Amanda Jung, Global Institute of Sustainability	2010-present
Elizabeth Marquez, Global Institute of Sustainability	2005-present
Brian Murphy, Global Institute of Sustainability	2009-present
Helen Palmaira, Global Institute of Sustainability	2006-2008
James Quinn, Global Institute of Sustainability	2007-2008
Barry Redmond, Global Institute of Sustainability	2008-2010
Susan Siddell, Global Institute of Sustainability	2010-present
Shirley Stapleton, Global Institute of Sustainability	1997-2005
Kathleen Stinchfield, Global Institute of Sustainability	1997-2007
Megan Wilkins, Global Institute of Sustainability	2007-2008
Linda Williams, Global Institute of Sustainability	1997-present
Cindy Zisner, Global Institute of Sustainability	1997-present
Graduate Research Associates	
Jeffrey Ackley, Life Sciences/IGERT	2009-present
Carol Atkinson-Palumbo, Geographical Sciences/IGERT	2004-2007
Stacy Avent, Human Evolution and Social Change	2007-2008
Marea Baggetta, Life Sciences/IGERT	2004-2005
Christofer Bang, Life Sciences	2006-present
Melanie Banville, Applied Sciences and Mathematics	2009-present
Troy Benn, Engineering/IGERT	2006-present
Wendy Bigler, Geographical Sciences	2004-2007
Robert Bills, Life Sciences	2004-2006
Jessica Block, Earth and Space Exploration	2005-2006
Ed Burgess, Sustainability/IGERT	2009-present
Kendra Busse, Life Sciences	2006-2010
Alexander Buyantuyev, Life Sciences	2002-2008
Yolanda Chavez-Cappellini, Languages and Literatures	2006
Chichi Choi, Engineering	2007-2009
James Clancy, Geographical Sciences/IGERT	2004-present
Robin Cleland, Human Evolution and Social Change/IGERT	2008-present
Winston Chow, Geographical Sciences	2007-present
Tim Collins, Geographical Sciences/IGERT	2000-2006
Shannon Conley, Public Policy	2008-present
Elizabeth Cook, Life Sciences/IGERT	2007-present
Bethany Cutts, Life Sciences	2006-2010
Kate Darby, Human Evolution and Social Change/IGERT	2006-present

Rachel Davies, Life Sciences	2006-2008
Scott Davies, Life Sciences	2009-present
Juan H. Declet, Geographical Sciences	2006
Xiaoli Dong, Sustainability	2009-present
Christopher Eisinger, Earth and Space Exploration/IGERT	2003-2005
Michelle Elliott, Human Evolution and Social Change/IGERT	2001-2004
Vanessa Escobar, Earth and Space Exploration	2006
Elizabeth Farley-Metzger, Human Evolution and Social Change	2004-2007
Haralambos Fokidis, Life Sciences	2007-present
Jessica Fox, Sustainability	2009
Sheila Fram, Institute for Social Science Research	2006
Erin Frisk, Sustainability	2008-present
Kristin Gade, Life Sciences/IGERT	2004-present
Daniel Gerrity, Engineering/IGERT	2004-2006
Ted Gilliland, Sustainability/IGERT	2009-present
Daniel Gonzales, Engineering	2005-2007
Praveen Gorthy, Computer Science	2009
Sara Grineski, Human Evolution and Social Change/IGERT	2001-2006
Arijit Guhu, Sustainability/IGERT	2009-present
Anne Gustafson, History/IGERT	2005-2008
Rebecca Hale, Life Sciences	2007-present
George Alexander Hamilton, Chemistry and Biochemistry	2008-present
Tamara Harms, Life Sciences	2004-2007
Donna Hartz, Geographical Sciences/IGERT	2005-present
Brent Hedquist, Geographical Sciences/IGERT	2005-present
Allison C. Huang, Student worker	2004-2006
Scott Ingram, Human Evolution and Social Change/IGERT	2003-present
Darrel Jenerette, Life Sciences	2000-2004
Ben Jewell, Human Evolution and Social Change/IGERT	2009-present
Sheela Kanwar, Computer Sciences	2010
Shai Kaplan, Geographical Sciences and Urban Planning	2009-present
Alethea Kimmel-Guy, Geographical Sciences	2006-2008
Elisabeth Larson, Life Sciences/IGERT	2004-present
Susannah Lerman, Natural Resources Conservation, U Mass	2006-present
Jen Litteral, Life Sciences	2007-2009
Matthew Lord, Geographical Sciences/IGERT	2001-2006
Tracy Lund, Earth and Space Exploration	2007-present
Yevgeniy Marusenko, Life Sciences	2007-present
Wendy Marussich, Life Sciences	2000-2004
Brandon McLean, Earth and Space Exploration	2005-2007
Cathryn Meegan, Human Evolution and Social Change/IGERT	2003-present

James Miller, Geographical Sciences/IGERT	2003-2007
Thad Miller, Sustainability/IGERT	2006-present
Chad Monfreda, Life Sciences/IGERT	2008-present
Tisha Munoz, Sustainability/IGERT	2006-present
David Murillo, Mathematics and Statistics/IGERT	2007-present
Kaesha Neil, Life Sciences	2006-2008
Scott Norby-Cedillo, Sustainability/IGERT	2007-present
Aura Ontiveros, Applied Biological Sciences	2007-2009
Yun Ouyang, Life Sciences	2008-present
Katelyn Paraday, Human Evolution and Social Change/IGERT	2009-present
John Parker, Human Evolution and Social Change/IGERT	2001-2006
W. John Roach, Life Sciences/IGERT	1999-2006
Darren M. Ruddell, Geographical Sciences	2006-2009
Avraj Sandhu, Computer Science	2006
Nilavan Sarveswaran, Engineering	2006
Hoski Schaafsma, Life Sciences/IGERT	2003-2009
Shade Shutters, Life Sciences/IGERT	2003-present
Catherine Singer, Life Sciences	2005-2007
Arthur Stiles, Life Sciences	2002-2006
Colleen Strawhacker, Human Evolution and Social Change/IGERT	2006-present
Steve Swanson, Human Evolution and Social Change/IGERT	2001-present
Ken Sweat, Life Sciences	2006-present
Philip Tarrant, Geographical Sciences	2005-2006
Carissa Taylor, Sustainability	2009-present
Laura Taylor-Taft, Life Sciences	2006-2009
Nathan Toke, Engineering/IGERT	2006-present
Roger Tomalty, Geographical Sciences	2004-present
Jolene Trujillo, Life Sciences	2007-present
Eli Tural, Geographical Sciences and Urban Planning	2009-present
Kelly Turner, Geographical Sciences/IGERT	2007-present
Deva Visamsetty, Computer Science and Engineering	2007-2008
Jason Walker, Life Sciences/IGERT	2005-2008
Benjamin Warner, Life Sciences	2009-present
Christina Wong, Life Sciences	2008-present
Jacqueline White, Life Sciences	2004-2006
Peng Zhang, Engineering	2006-2007
Sainan Zhang, Sustainability	2009-present
Xiaoding Zhuo, Chemistry and Biochemistry	2005-present
Undergraduate Student Workers	
Melinda Alexander, Institute for Social Science Research	2006

Cristian Aquino-Sterling, Institute for Social Science Research	2006
Rosario Armenta, Institute for Social Science Research	2006
Humberto Badillo, Global Institute of Sustainability	2007
Mandana M. Behbahani, Life Sciences lab	2006
Kallista Bernal, Institute for Social Science Research	2006
Karyn Boenker, Global Institute of Sustainability	2008
David Borough, Institute for Social Science Research	2006
Julianna Bozler, Service at Salado	2007-2008
Molly Brennan, Institute for Social Science Research	2006
Hillary Butler, Service at Salado	2006
Jaleigh Brumand, Global Institute of Sustainability	2010
Matthew Cavazos, Institute for Social Science Research	2006
Christina Cole, Institute for Social Science Research	2006
Marc Contijoch, Institute for Social Science Research	2006
Jordan Costello, Service at Salado	2007
Kimberly Cronin, Institute for Social Science Research	2006
Arturo Diaz Hernandez, Institute for Social Science Research	2006
Karla Dille, Institute for Social Science Research	2006
Bradley Durham, Institute for Social Science Research	2006
Courtney Edel, Life Sciences lab	2007-2008
Bryana Edgell, Life Sciences lab	2009-present
Wilford Eiteman-Pang, Service at Salado	2007
Alexandra Flournoy, Service at Salado	2007
Cassandra Fronzo, Institute for Social Science Research	2006
Justin E. Goering, Global Institute of Sustainability	2004-2005
Jonathan Gonzalez, Institute for Social Science Research	2006
Jocelyn Hackett, Institute for Social Science Research	2006
Travis Hitchner, Life Sciences lab	2008-2009
Amy M. Hodge, Global Institute of Sustainability	2004-2005
Celeste Holm, Global Institute of Sustainability	2009-2010
Daniel Hoyt, Service at Salado	2007
Dillan Isaac, Institute for Social Science Research	2006
Christopher Jarzabek, Service at Salado	2007
Ruth Jensen, Institute for Social Science Research	2006
Marsha Johnson, Service at Salado	2007
Kevin King, Institute for Social Science Research	2006
Crissy Knight, Service at Salado	2007
Mark Leeper, Institute for Social Science Research	2006
Mildred Levine, Institute for Social Science Research	2006
Danielle Lindsey, Institute for Social Science Research	2006
Kathryn Mayer, Global Institute of Sustainability	2008

Nazune Menka, Service at Salado	2006
Erin M. Mills, Global Institute of Sustainability	2002-2007
Lindsey Miller, Institute for Social Science Research	2006
Clifford Millett, Service at Salado	2006
Kathleen M. Mills, Global Institute of Sustainability	2004-2005
Hanna Milosevic, Service at Salado	2007
Rebecca Minghelli, Service at Salado	2007
Jennifer Monninger, Institute for Social Science Research	2006
Sandra L. Muldrew, Global Institute of Sustainability	2004-2005
Keith Mulvin, Service at Salado	2007
Casey Oakes, Service at Salado	2006
Sean O'Reilly, Service at Salado	2007
Viswesh Parameswanan, Global Institute of Sustainability	2006
Jason Parker, Service at Salado	2007
Chiranjeevi Pavurala, Global Institute of Sustainability	2006-2007
Erika Paulus, Service at Salado	2007
Danielle L. Prybylek, Global Institute of Sustainability	2004-2006
James Quinn, Institute for Social Science Research	2006
Roxanne C. Rios, Global Institute of Sustainability	2004-2005
Jennifer C. Roberts, Global Institute of Sustainability	2004-2006
Juan Rodriguez Martin, Institute for Social Science Research	2006
Heather K. Rothband, Global Institute of Sustainability	2006
Amanda Russell, Global Institute of Sustainability	2010
Sean Russell, Institute for Social Science Research	2006
Matthew Salem, Global Institute of Sustainability	2008
Janaina Scannell, Institute for Social Science Research	2006
Sharon Schleigh, Service at Salado	2006
Rosie Servis, Global Institute of Sustainability	2005-2008
Nafis Shamsid-Deen, Service at Salado	2007
Krystin Sheekey, Institute for Social Science Research	2006
Alex Silva, Service at Salado	2007
Sone P. Sithonnorath, Life Sciences lab	2005
Myra Snodgrass, Service at Salado	2007
Rebecca Sommer, Service at Salado	2007
Cynthia Soria, Service at Salado	2006
Emily Starr, Service at Salado	2007
Grayson Steinberg, Institute for Social Science Research	2006
Carena Van Riper, Service at Salado	2007
Francisco Vargas, Institute for Social Science Research	2006
Julianne Vittal, Global Institute of Sustainability	2008
Benjamin Wachter, Service at Salado	2007

Randy Wagman, Institute for Social Science Research	2006
Jessica Webber, Global Institute of Sustainability	2010
Stephanie Williams, Institute for Social Science Research	2006
Research Experience for Undergraduates (REUs)	
Erin Adley, Life Sciences	2004
Bony Ahmed, Life Sciences,	2006-2007
Garth Baughman, Economics	2008
Nicole Broughton, Biology, Chicago State University	2008
Tejkaran Dhillon, Biology and Society	2008
Michelle Ashley Gohr, Life Sciences	2007-2008
Annie Hale, Sustainability	2010
Megan Kelly, Chemistry	2006-2007
Genevieve Luikart, Environmental Studies, New College of FL	2007
Kathryn McCormick, Life Sciences	2007
Hannah Mensing, Geography	2007-2008
Andrew Miller, St. Olaf College	2007
Vivian Miller, Life Sciences	2007
Patrick Ortiz, Life Sciences	2007
Matthew Salem, Geography	2008-2009
Shondra L. Seils, Ecology and Evolutionary Biology, U of AZ	2006
Erica Schwartzmann, Life Sciences	2006-2007
Michelle Schmoker, Life Sciences	2010
Kristina Waterbury, Life Sciences	2004
Hilary Waterman, Engineering	2008
Christina Wong, SEEDS student, Occidental College	2006
Thomas M. Zambo, Life Sciences	2006
Ecology Explorers Teachers	
Jodi Alder, Mesquite High School	2009
Josh Applebach, Mesquite High School	2009
Stephanie Arnold, Veritas Preparatory Academy	2005
Amy Bell, Arcadia High School	2005
Gerald Bell, Perry High School	2010
Marissa Boomgaard, Westwood High School	2009
Debra Bornstein, Desert Sage Elementary School	2005
Kristy Braaksma, Desert Ridge Junior High	2005
John Brands, Desert Ridge Junior High	2005
Kris Brimhall, Mesquite High School	2009
Matthew Burke, Trevor G Browne High School	2007
Rochelle Burson, Mesquite High School	2009

Shane Bycott, Skyline High School	2010
Sonia Campbell, Galveston Elementary School	2010
Shiloh Carroll, Highland High School	2006
Kara-Anne Carpenter, Chandler Prepratory Academy	2006
Sean Cederstrom, CTA Freedom	2010
Patricia Clinch-York	2010
Barbara Cortez, Mesquite High School	2009
Melissa Couitt, Galveston Elementary	2010
Cathy Culver, Chander High School	2010
Thomas K. Daniels, Kyrene Akimel A-Al Middle School	2005
Kim Davis, Highland High School	2009
Christine Day, Brimhall Jr. High School	2010
Amy Dean, Kyrene del Milenio	2008
John Dole, Mesquite High School	2009
Daryl Dubas, Mesquite High School	2009
Fe Dumapias, North High School	2009
Mary Ellis, Mesquite High School	2009
Cher Fesenmaier, Desert Mountain High School	2005
Annette Fields, Gilbert High School	2009
Dan Fortney, Bogle Junior High School	2010
Kathryn Frederick, Queen Creek High School	2007
Eileen Geronimo, Mesquite High School	2009
Kendall Gilliland, Mountain Pointe High School	2009
Taylor Hale, Highland High School	2009
Sharon Harrison, Vista Verde Middle School	2006
Kathleen Hartnett, Alta E Butler School	2005
Sandra Hay, Hartford Elementary School	2010
Anne Hudson, Mesquite High School	2009
Bruce Jones, Brimhall Jr. High School	2010
John Jung, Mesa High School	2007
Kimber Kay, Ingleside Middle School	2006
Jackie Kimzey, Stapley Jr. High School	2010
Jennifer Knudsen, Mesa Jr. High School	2010
Karly Kocks, Kyrene de la Mirada	2008
Larry Langstaff, Hendrix Jr. High School	2010
Lisa Lasch, Highland High School	2009
Roger LeBlanc, Mountain Pointe High School	2009
Karen Lee, Goodman Elementary School	2010
Melissa Mara, Sandra Day O’Conner High School	2006-2007
Stephanie Maynard, Queen Creek High School	2007
Christin McLellan, Willow Canyon High School	2007

Laura Moore, Kyrene de la Mariposa	2008
Stephanie Morgan, Perry High School	2007, 2010
Caryn Morrison, Mesquite High School	2009
Peggy Ostrander, Brimhall Jr. High School	2010
Diana Perez, Andersen Jr. High School	2010
Shannon Plaisted, Ishikawa Elementary	2010
Debbie Raber, Hamilton High School	2010
Linda Riggs, Augusta Ranch Elementary	2006
Dorothy Ruot, Desert Ridge High School	2009
La Rinda Saylor, Kyrene del Cielo	2008
Sheila Scanlan, Highland High School	2009
Rosemary Schlechty, Willis Jr. High School	2010
Michele Schiff, Ironwood High School	2005
Karen Smeltzer, Kyrene del Cielo	2008
Clarice Snyder, Camelback High School	2005
Jeffrey Snyder, Washington High School	2005
Sharon Solberg Ayers, Kyrene de la Mariposa	2008
Lynn Stinson-Keys, Tempe Preparatory Academy	2005
Kiva Stone, Frank Borman Middle School	2005
Jil-Christi Tatar, Frye Elementary School	2010
Jeffrey Taylor, Mesquite Jr High School	2005
Karen Thompson, Kyrene del Sureno	2008
Linda Tschida, Basha High School	2010
Aaron Ullman, Red Mountain High School	2007
Melina Vibber, Kyrene del Cielo	2008
Cheryl Vitale, Mesquite Jr High School	2006
Kim Wallis-Lindvig, Boulder Creek High School	2006
Heather Walterson, Chandler High School	2010
Kathy Weil, Shumway Elementary	2010
Melissa Wendell, Mountain Pointe High School	2009
Sheila Wilson, Andersen Jr. High School	2010
Jamie Wilson-Fioramonti, Highland High School	2009
Roy Yates, Andersen Jr. High School	2010
Cheryl Zastrow, Kyrene Monte Vista	2008
Community Partners	
Arizona Audubon	
Arizona Dept. of Water Resources	
Arizona Dept. of Environmental Quality	
Arizona Dept. of Game and Fish	

Arizona Foundation for Resource Education	
Arizona Public Service	
Arizona Science Center	
Arizona State Land Dept.	
Boys Hope Girls Hope	
City of Phoenix	
City of Scottsdale	
City of Tempe	
Creighton School District	
Deer Valley High School District	
Desert Botanical Garden	
Flood Control District of Maricopa County	
Fountain Hills High School District	
Gila River Community Schools	
Gilbert Public Schools	
Gilbert Riparian Preserve	
Glendale School District	
Kyrene School District	
Maricopa Association of Governments	
Maricopa Community Colleges	
Maricopa Parks and Recreation Department	
Mesa Public Schools	
Peoria Unified School District	
Phoenix College	
Phoenix Elementary School District	
Phoenix Union High School District	
Roosevelt School District	
Salt River Project	
Sonoran Desert Center	
Tempe Elementary School District	
Tempe Preparatory Academy	
Tempe Union High School District	
The Phoenix Zoo	
Tonto National Forest	
US Dept. of Agriculture	
US Forest Service	
US Geological Survey	

Veritas Preparatory Academy	
Organizations Giving Permission for Sampling on Their Sites	
Arizona Dept. of Environmental Quality	
Arizona Public Service	
Arizona Dept. of Transportation	
Arizona State Land Dept.	
Arizona State Parks	
City of Phoenix	
City of Chandler	
City of Scottsdale	
City of Tempe	
Dawn Lake Homeowners Association	
Desert Botanical Garden	
Dobson Ranch Homeowners Association	
Duncan Family Farms	
Flood Control District of Maricopa County	
Honeywell	
Intel	
Insight Enterprises	
Las Brisas Homeowners Association	
Maricopa Co. Dept. of Environmental Services	
Maricopa Co. Parks and Recreation Dept.	
Morrison Brothers Farms	
Ocotillo Homeowners Association	
Ross Management Inc.	
Salt River Project	
Sonoma Farms, Inc.	
Tempe Union High School District	
Tonto National Forest	
Town of Fountain Hills	
US Forest Service	
US Geological Survey	
Val Vista Lakes Community Association	
Valley Lutheran Hospital	

APPENDIX B:
LONG-TERM MONITORING AT CAP LTER

Monitoring Program	Number of Sampling Locations	Sampling Frequency	Variables Measured
Arthropods	31 sites	Quarterly	• Ground-dwelling arthropods
Birds	56 core sites	Semiannually (Jan, Mar)	• Point-count bird census
Birds	40 PASS neighborhoods	Semiannually (Dec, Feb)	• Point-count bird census
Tree survey	50 sites	Annually (winter)	• Tree biovolume • Tree condition
Survey 200	204 sites	Five years (spring)	• Photo documentation • Vegetation composition • Vegetation cover • Soil: physical, chemical and biological • Habitat/built structure • Human activity
North Desert Village	4 treatment areas	Continuous	• Air temperature • Ground surface temperature • Soil temperature • Soil heat flux • Soil water content
North Desert Village	4 treatment areas	Monthly	• Landscape water use • Electricity use • Dwelling surface temperature
North Desert Village	4 treatment areas	Annually, with exception of bird and arthropod monitoring (as above)	• Birds • Arthropods • Primary productivity
Atmospheric deposition	15 locations (upwind, core, and downwind of greater Phoenix)	Quarterly	• Wet & dry nitrogen deposition
Desert flora productivity	15 locations (upwind, core, and downwind of	Semiannually (spring and fall)	• Productivity (stem length growth) of Creosote

Monitoring Program	Number of Sampling Locations	Sampling Frequency	Variables Measured
	greater Phoenix)		(*Larrea tridentata*) • Productivity (biomass harvesting) of annual plants
Desert soil chemistry	15 locations (upwind, core, and downwind of greater Phoenix)	Semiannually (spring and fall)	• Nutrients, and major cations and anions
Water-quality monitoring	5 locations at major influent (Salt and Verde Rivers, CAP canal) and effluent (Salt and Gila Rivers) systems	Bimonthly	• Nutrients • Major cations/anions • pH • Temperature • Specific conductance • Particulates
Groundwater-quality monitoring	Single experimental plot along Gila River	Bimonthly	• Water quality
Stormwater monitoring	Single location at outflow of Indian Bend Wash	Flow-weighted sampling of each runoff-producing storm	• Water quality
Land-use and land-cover	CAP LTER site	Every five years	• Land use change • Land cover change
Microclimate	AZMet stations	Data mined as needed	• Growth and intensity of urban heat island • Decline in frosts and freezes
Microclimate	2 locations corresponding to atmospheric deposition study sites	Continuous	• Standard suite of meteorological variables
Phoenix Area Social Survey (PASS)	40 neighborhoods	Five years	• Water supply and conservation • Land use, preservation and growth management • Air quality and transportation • Climate change and the urban heat island