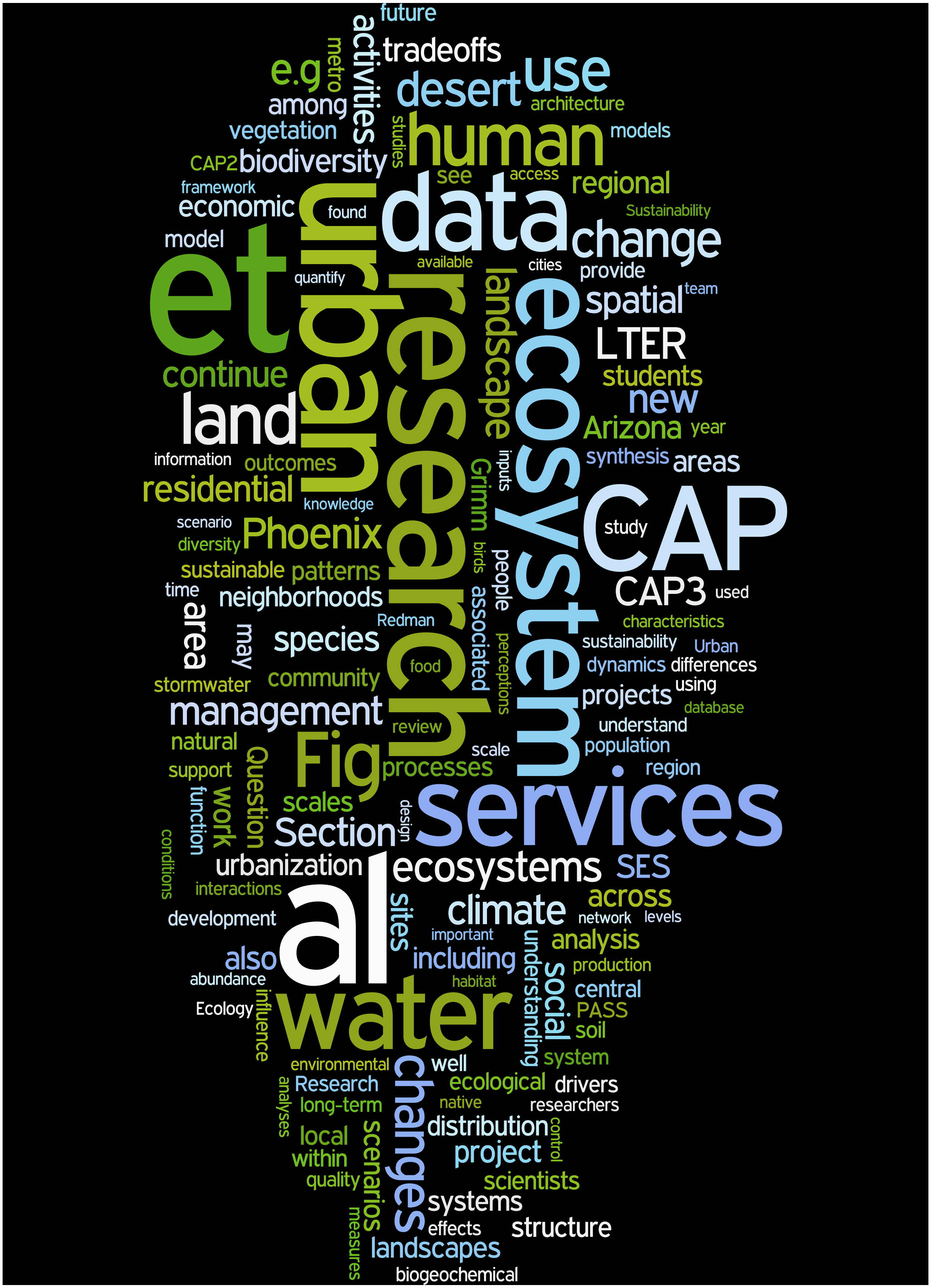

future
activities
metro
tradeoffs
e.g
use
desert
architecture
among
studies
human
models
vegetation
CAP2
biodiversity
see
access
regional
framework
urban
data
Sustainability
economic
found
change
model
et
research
available
cities
provide
quantify
landscape
ecosystem
spatial
team
LTER
continue
students
new
land
Arizona
year
information
outcomes
inputs
synthesis
areas
residential
Grimm
knowledge
CAP
study
scenario
diversity
Phoenix
birds
people
sustainable
patterns
CAP3
used
time
neighborhoods
associated
area
may
Redman
characteristics
species
sustainability
Urban
food
perceptions
dynamics
differences
stormwater
community
projects
using
management
database
review
understand
natural
population
Fig
scale
support
Question
processes
region
work
function
scales
design
services
Section
conditions
urbanization
ecosystems
SES
interactions
al
across
development
sites
climate
network
levels
important
analysis
also
including
understanding
production
abundance
habitat
social
central
Ecology
influence
water
PASS
soil
system
environmental
well
ecological
drivers
analyses
Research
changes
native
researchers
long-term
local
scenarios
distribution
control
within
project
quality
scientists
systems
measures
effects
structure
landscapes
biogeochemical

Table of Contents

Project Summary

List of Participants

Project Description

Part 1 – Results of Prior NSF LTER Support

Part 2 – Proposed Research

Part 3 – Project Management

Part 4 – Information Management

Part 5 – Education and Outreach

Literature Cited

List of Acronyms and Abbreviations

List of Products

List of Datasets

List of Letters of Collaboration

Project Summary

CAP3: Urban Sustainability in the Dynamic Environment of Central Arizona

As the long-term study of rapidly urbanizing central Arizona reaches the 12-year mark, the critical importance of cities as a source of both problems and potential solutions to the global sustainability challenge has come into focus. Accordingly, CAP's central question has evolved to reflect this emphasis: How do the services provided by evolving urban ecosystems affect human outcomes and behavior, and how does human action (response) alter patterns of ecosystem structure and function and, ultimately, urban sustainability, in a dynamic environment? Working from a conceptual framework that links the social and ecological spheres of urban socioecological systems via ecosystem services, CAP will continue to build foundational databases of land-use and land-cover change, human attitudes and perceptions with respect to the environment, an extensive snapshot of ecological variables across the 6400-km^2 study area, household- and neighborhood scale responses to experimental manipulation of residential landscapes, and demographic and economic variables. Based on these foundations, ongoing and new research is proposed in four Integrative Project Areas: *Climate, Ecosystems and People; Water Dynamics in a Desert City; Biogeochemical Patterns, Processes, and Human Outcomes;* and *Human Decisions and Biodiversity*. Finally, new activities are proposed to both synthesize >12 years of existing data and to work with other scientists, decision makers, and the public in co-producing a vision for a sustainable future in central Arizona.

CAP contributes to scientific understanding by developing and testing theory of socioecological systems for the urban case, using a place-based, transdisciplinary approach. The long-term database will be further developed and used to test new hypotheses about ecosystem services in designed and highly modified urban environments. New work on land cover will include three distinct scales (parcel, metropolitan, regional "megapolitan"), adding object-based analysis of high-resolution imagery to address questions about ecosystem services associated with different land configurations (architectures), vegetation–water–heat interactions, and movement of water during storms. Water-related projects bring new hydrologic expertise and models to bear on questions of landscape redistribution of water and connectivity, ecosystem services, and "virtual water." Biogeochemical research will continue to focus on altered cycles, but will add analysis of persistent organic pollutants. A new perspective of "the urban food web" will organize biodiversity research, which continues to focus on mechanistic explanations for biodiversity change in the face of urbanization. Throughout much of this work, CAP will launch systematic treatments of tradeoffs among ecosystem services and between those services and human outcomes.

CAP's **broader impacts** include: 1) raising scientists' and decision-makers' awareness of cities as socioecological platforms for solving sustainability challenges; 2) integrating education and outreach at all levels into our programs; 3) continuing to develop and maintain a comprehensive, long-term database of ecological and social variables for a rapidly changing system; and 4) co-producing knowledge with community and governmental decision-makers. CAP has been an exemplar of transdisciplinary approaches, both within the LTER network and in several environmental science disciplines (Impact 1). Ecology Explorers, CAP's K-12 education-outreach program, will continue its work with teachers and will partner with our new GK12 and other intiatives to bring ecology into sustainability education (Impact 2). At the close of our 12-y IGERT program in urban ecology, CAP and other graduate students have formed their own group, "Graduates in Integrative Society and Environment Research," with which CAP will partner to establish a graduate mini-grant program (Impact 2). Information management will ensure long-term integrity and accessibility of the CAP database, while also developing new tools to interface land-cover and socioecological databases (Impact 3). Finally, scenario development will strongly engage related projects, community partners, and local and regional decision-makers in envisioning a sustainable future for the central Arizona urban socioecological system (Impact 4).

CAP3 Participants

Co-Principal Investigators/Executive Committee

Nancy Grimm	Life Sciences	Ecology
Christopher Boone	Sustainability; Human Evolution & Social Change	Geography
Dan Childers	Sustainability	Ecology
Sharon Harlan	Human Evolution & Social Change	Sociology
Charles Redman	Sustainability; Human Evolution & Social Change	Anthropology
Billie Turner	Geographical Sciences & Urban Planning	Geography

Co-Principal Investigators

David Casagrande	Western Illinois U. – Sociology & Anthropology	Anthropology
Susanne Grossman-Clarke	Global Institute of Sustainability	Climatology
Sharon Hall	Life Sciences	Ecology
Kelli Larson	Geographical Sciences & Urban Planning; Sustainability	Geography
Chris Martin	Applied Sciences & Mathematics	Horticulture
Ray Quay	City of Phoenix	Planning
John Sabo	Life Sciences	Ecology
Kerry Smith	Business	Economics
Paige Warren	U. Mass. Amherst – Natural Resources Conservation	Ecology
Paul Westerhoff	Sustainable Engineering & the Built Environment	Engineering
Jianguo Wu	Life Sciences; Sustainability	Ecology
Abigail York	Human Evolution & Social Change	Political Science

Senior Personnel

Josh Abbott	Sustainability	Economics
Rimjhim Aggarwal	Sustainability	Economics
Luc Anselin	Geographical Sciences & Urban Planning	Geography
Ramon Arrowsmith	Earth & Space Exploration	Geomorphology
George Basile	Global Institute of Sustainability	Planning
Heather Bateman	Applied Sciences & Mathematics	Conservation Biology
Bob Bolin	Human Evolution & Social Change	Sociology
Anthony Brazel	Geographical Sciences & Urban Planning	Climatology
Pierre Deviche	Life Sciences	Physiology
Stevan Earl	Global Institute of Sustainability	Ecology
Monica Elser	Global Institute of Sustainability	Education
Stan Faeth	U. North Carolina-Greensboro – Biology	Ecology
Eli Fenichel	Life Sciences	Ecology/Economics
Janet Franklin	Geographical Sciences & Urban Planning; Life Sciences	Ecology
Matt Fraser	Sustainability	Engineering
Patricia Gober	Geographical Sciences & Urban Planning; Sustainability	Demography
Hilairy Hartnett	Earth & Space Exploration; Chemistry & Biochemistry	Biogeochemistry
Darrel Jenerette	U. Calif. Riverside – Botany and Plant Sciences	Ecology
Chad Johnson	Mathematics & Natural Sciences	Ecology
Darren Julian	Arizona Game & Fish Department	Conservation Biology
Jason Kaye	Penn State – Crop and Soil Sciences	Ecology
Tim Lant	Global Institute of Sustainability	Modeling
Kathleen Lohse	U. of Arizona – Natural Resources & the Environment	Ecology
Anandamayee Majumdar	Mathematical & Statistical Sciences	Statistics
Melissa McHale	North Carolina State U. – Forestry and Natural Resources	Ecology
Soe Myint	Geographical Sciences & Urban Planning	Geography
Marcia Nation	Global Institute of Sustainability	Geography
Carol Raish	US Forest Service, Rocky Mountain Research Station	Sociology
Benjamin Ruddell	Engineering	Engineering
Eyal Shochat	Independent researcher	Ecology
Everett Shock	Earth & Space Exploration; Chemistry & Biochemisty	Biogeochemistry
Jean Stutz	Applied Sciences & Mathematics	Ecology
Philip Tarrant	Global Institute of Sustainability	Conservation Biology
Arnim Wiek	Sustainability	Sustainability
Amber Wutich	Human Evolution & Social Change	Anthropology
Enrique Vivoni	Sustainable Engineering & the Built Environment; Earth & Space Exploration	Hydrology

Part 1 – Results of Prior NSF LTER Support

DEB-0423704, Central Arizona–Phoenix LTER: Phase 2, 2004–2010, $5,453,038 including supplements. 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).

The 6,400-km^2 CAP study area in central Arizona incorporates metropolitan Phoenix, surrounding Sonoran Desert scrub, and rapidly disappearing agricultural fields (see Fig. 2.1). 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. We highlight accomplishments of selected projects in these areas.

Rapid urbanization in central Arizona. 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. 2006; Schaafsma and Briggs 2007; Fig. 1.1). Since 1970,

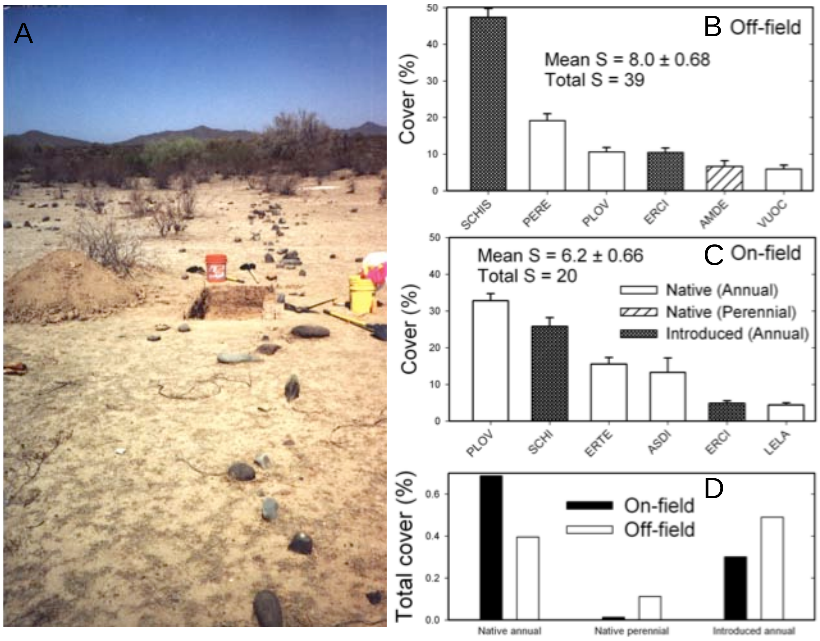


Figure 1.1. (A) One of the prehistoric agricultural fields at Cave Creek during the dry season, showing rock alignments (the remnants of a Hohokam water control feature for an irrigation canal). (B, C) Mean cover (±standard error) of the six dominant species in 0.25m^2 quadrats located on and off prehistoric 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.

rapid urbanization has led to a decline of arable land and a rise in urban (residential) land uses (Keys et al. 2007; Fig. 1.2). 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).

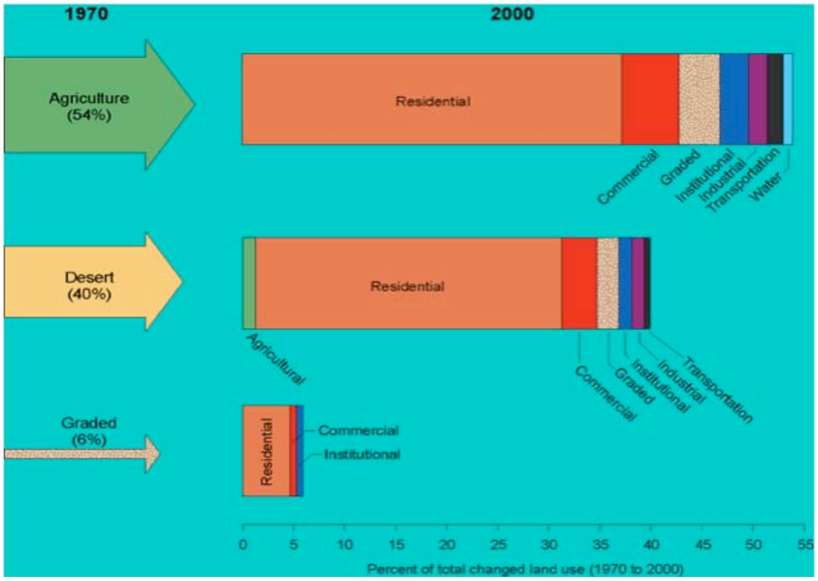


Figure 1.2. Analysis of the land transitions in CAP between 1970 and 2000 (after Keys et al. 2007).

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-b). 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 (Fig. 1.3). Our social-survey data reveal that race, gender, political persuasion, and time lived in Greater Phoenix govern perceptions about sprawl and influence support for policy prescriptions (York et al. in review-a).

Climate, ecosystems, and people. 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^{o}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).

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. 1.4). 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.

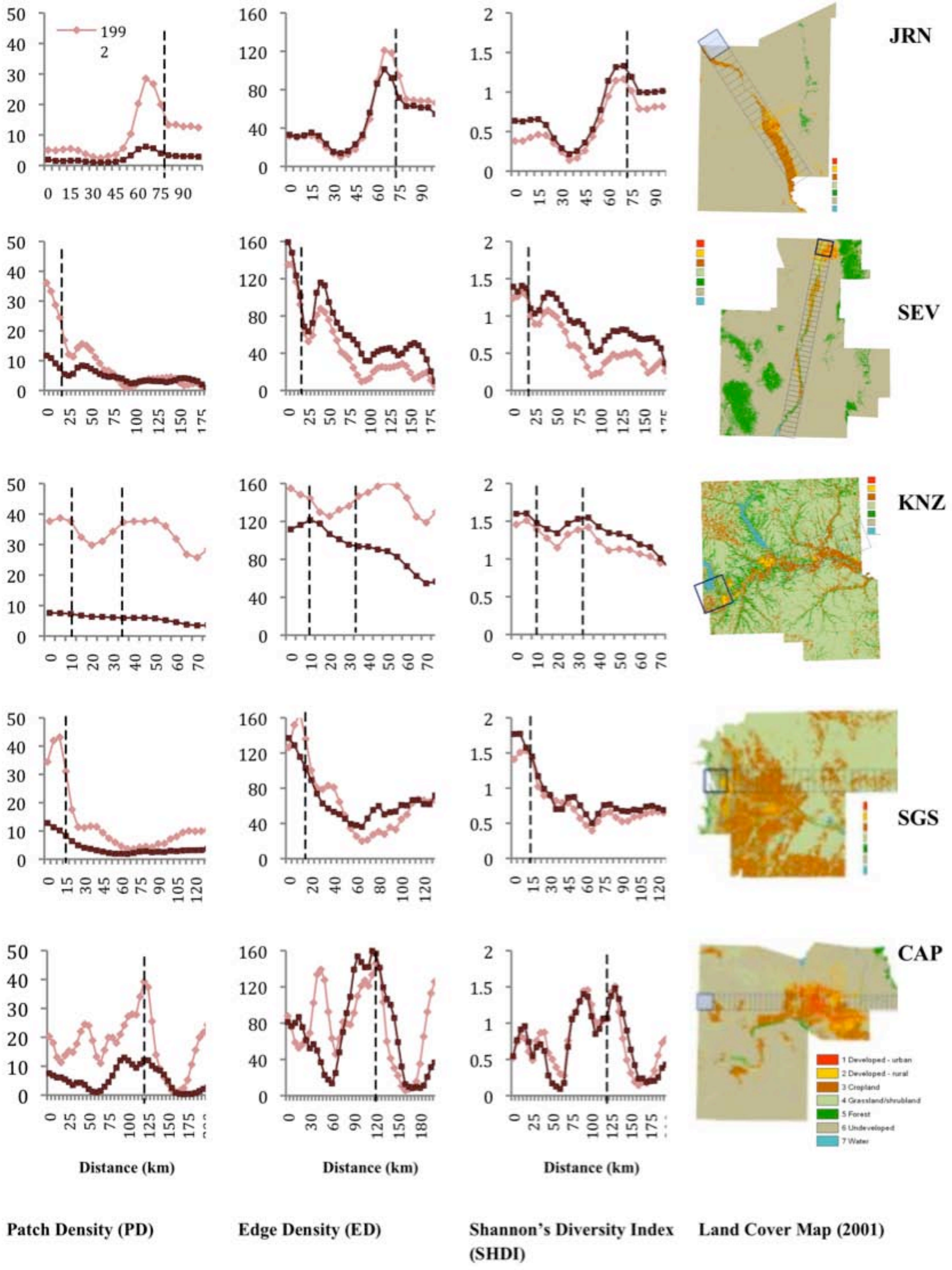
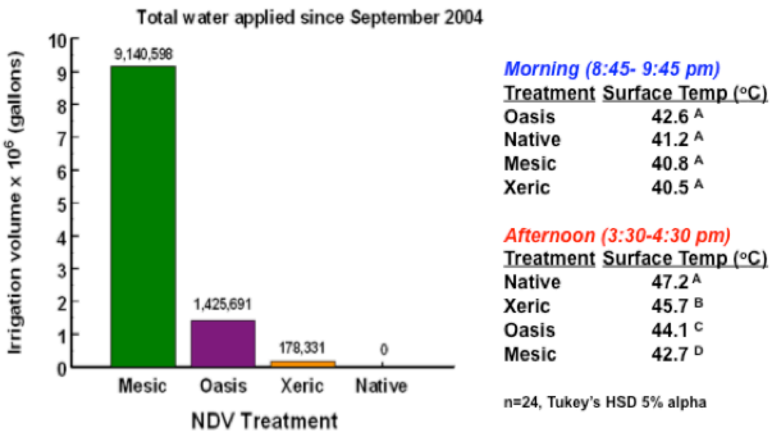


Figure 1.3. Spatial distribution of different landscape metrics at the landscape level along transects (shown on maps at right) for five LTER sites in 1992 and 2001.



Morning (8:45- 9:45 pm)

Treatment	Surface Temp (°C)
Oasis	42.6^{A}
Native	41.2^{A}
Mesic	40.8^{A}
Xeric	40.5^{A}

Afternoon (3:30-4:30 pm)

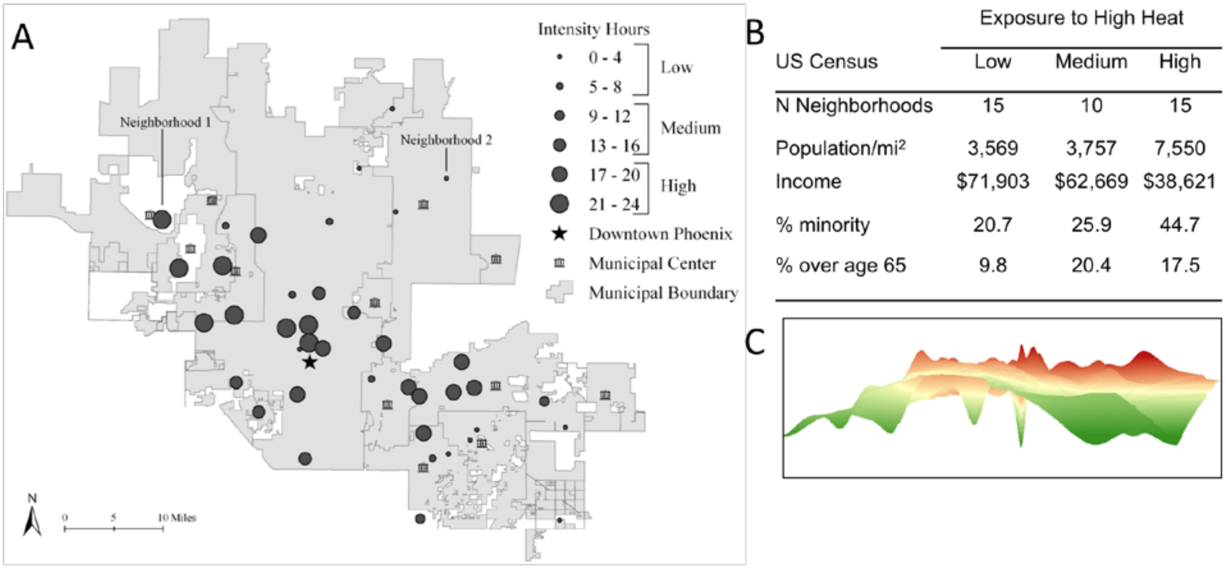
Treatment	Surface Temp (°C)
Native	47.2^{A}
Xeric	45.7^{B}
Oasis	44.1^{C}
Mesic	42.7^{D}

n=24, Tukey's HSD 5% alpha

Figure 1.4. 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.

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). 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*; Fig. 1.5).

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. in review). Our urban sites also showed a decoupling of phenology from precipitation, the main driver of phenologic change in the desert (Fig. 1.6). 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).



	Exposure to High Heat		
US Census	Low	Medium	High
N Neighborhoods	15	10	15
Population/mi^{2}	3,569	3,757	7,550
Income	$71,903	$62,669	$38,621
% minority	20.7	25.9	44.7
% over age 65	9.8	20.4	17.5

Figure 1.5. Spatial distribution of heat intensity in July 2005 (hours in a 4-d period that temperature exceeded 110^{o}F (A), demographic characteristics of the population in low-, medium- and high-exposure areas (B), and a graphic representation of the heat exposure "riskscape" for the region (C).

<u>*Water dynamics in a desert city.*</u> 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.

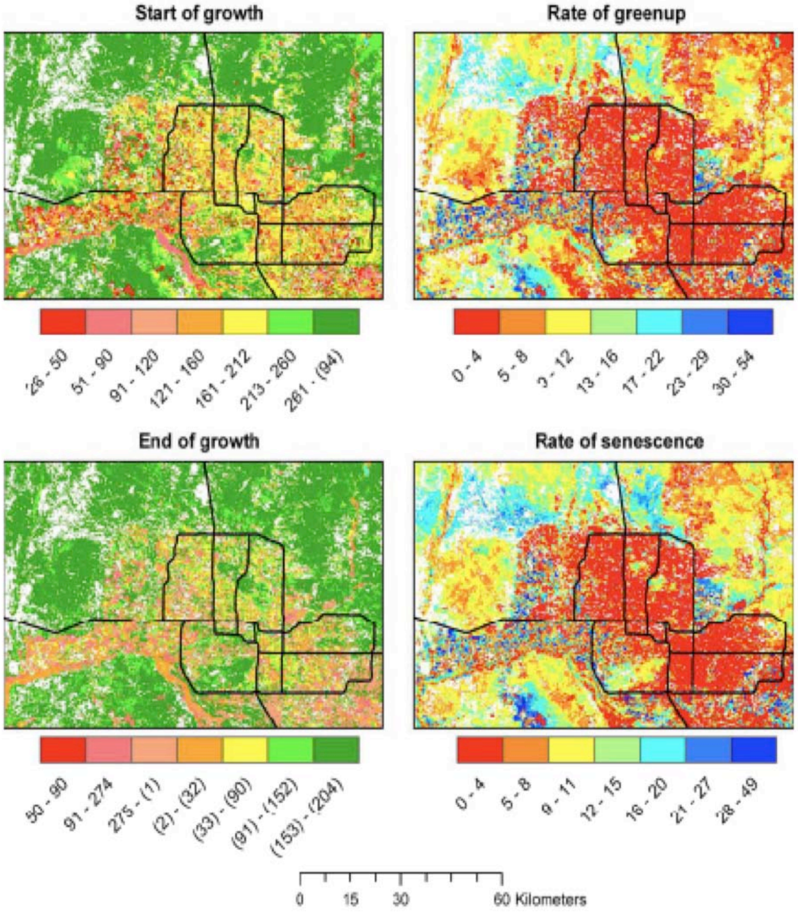


Figure 1.6. Seasonal parameters extracted from Savitsky-Golay filtered NDVI data. Start and end dates, rate of growth and senescence of the first growth period during 2004-2005. Dates are displayed as days of year (year 2005 days are shown in parentheses). Rates are calculated as tangent of slope between 20% and 80% levels of NDVI.

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).

Water use, vegetation, cooling, and inequitable UHI distribution provide an excellent example of ecosystem-service tradeoffs we will examine in greater detail in CAP3 (Fig. 1.4). 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).

Biogeochemical patterns, processes, and human outcomes. 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. 1.7). 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. 1.7; 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. 1.8). 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 major riverine sources (McLean 2007). At smaller spatial scales, variation in N transport is sensitive to a combination of catchment

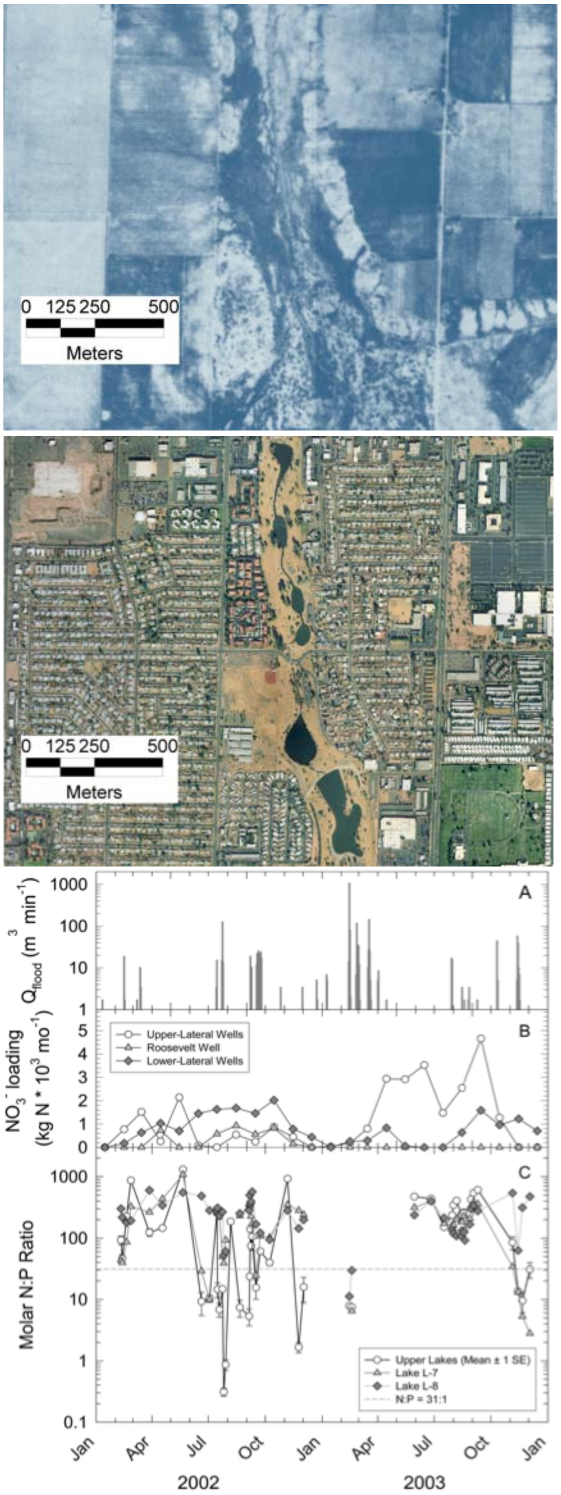


Figure 1.7. Change in ecosystem structure (photos) between 1949 and 2000 in IBW. Nutrient loading (B) and N:P (C: indicative of nutrient limitation) show dramatic shifts associated with storms (discharge increases in A).

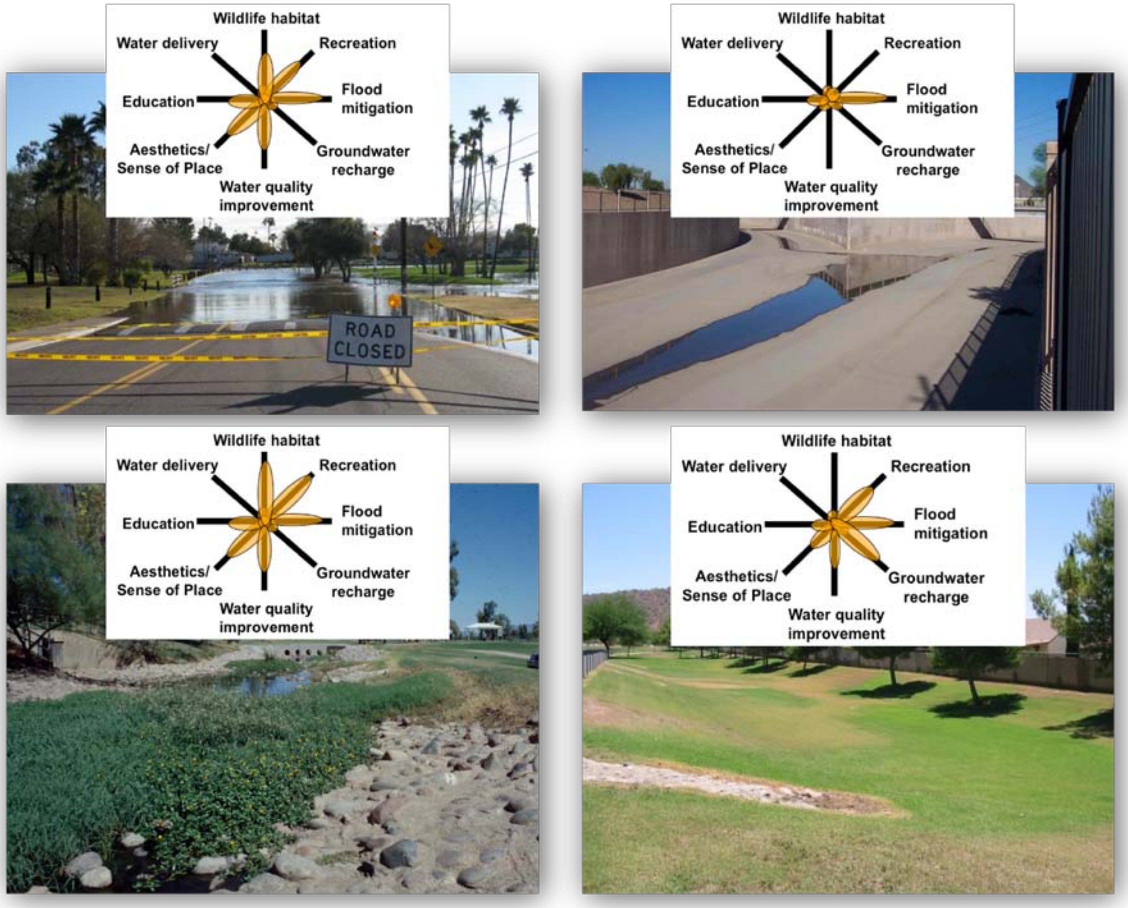


Figure 1.8. Photos of various stormwater management systems in metro Phoenix, with a conceptualization of the range of ecosystem services they provide (insets). Clockwise from top left: IBW floodway at a road crossing; flume design for stormwater removal; a mesic stormwater retention basin; and IBW at a golf course site. After E. Larson et al. (in review).

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. 1.9).

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. 1.10) than desert soils, and soil concentrations of lead (Pb), cadmium (Cd), copper (Cu), and arsenic (As) are correlated with urbanization (Fig. 1.11). 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. 1.12) and estimated that 1140 Gg of oC and 130 Gg 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

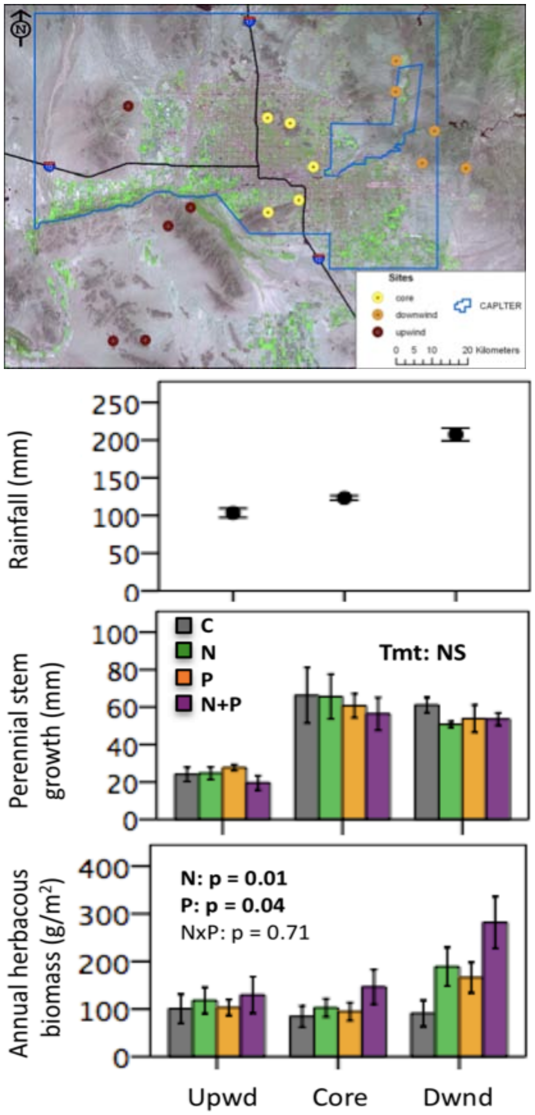


Figure1.9. Response of perennial and spring annual Sonoran Desert plants to experimental nutrient additions in sites across the Phoenix metropolitan area. Data shown for Spring 2008. C = Control; N = NH_4NO_3 addition; P = PO_4^{-3} additions as triple superphosphate; N+P = N and P in combination. Fertilization began in December 2005. N = 5 sites per region.

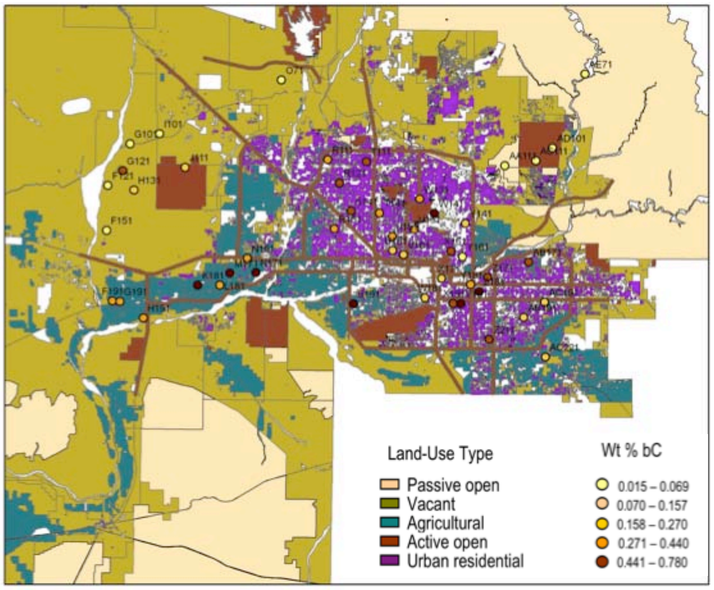


Figure 1.10. Distribution of bC across the CAP study area. Locations (circles) of soil survey sites are color-coded with darker shading indicating higher bC contents. Color overlays are general land-use classifications identified by Maricopa Association of Governments. H. Hartnett, unpublished.

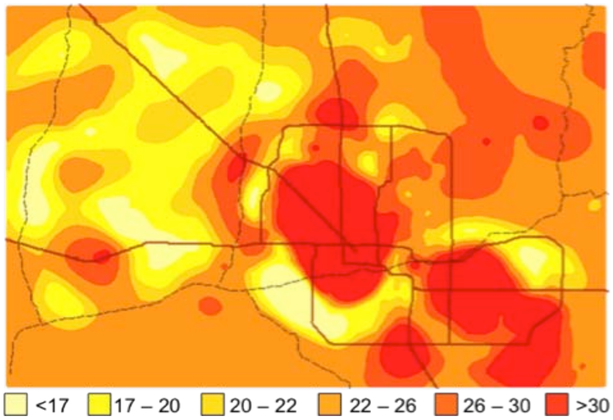


Figure 1.11. Lead concentration (µg/kg) measured in 2005 in the surface soil (1–10 cm) across CAP. Brown lines show major freeways; the urbanized region is encircled by these roads.

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 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. 1.13). Urban

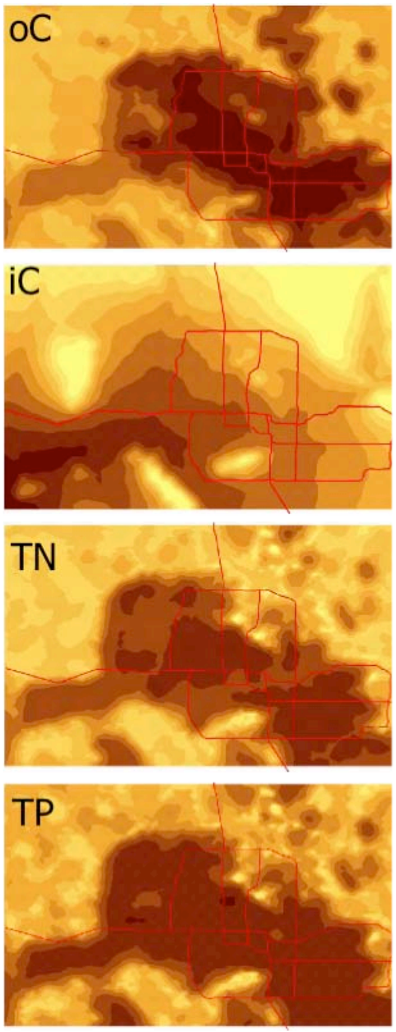


Figure 1.12. Patterns in carbon, nitrogen, and phosphorus across CAP. From Kaye et al. (2008).

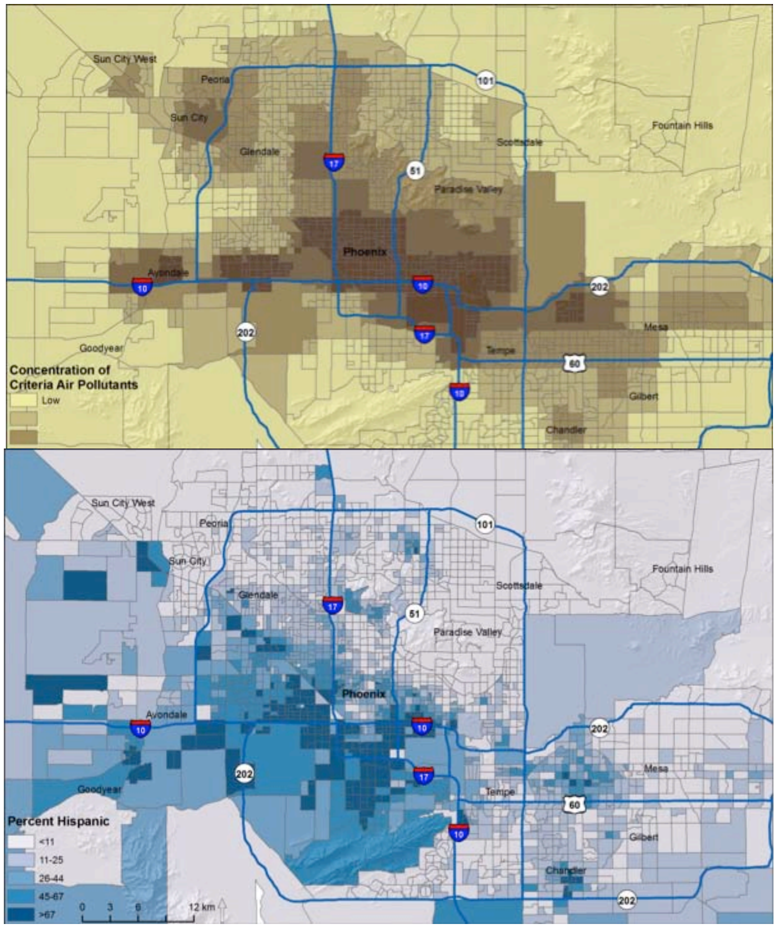


Figure 1.13. Spatial distributions of (top) criteria air pollutants and (b) percentage of the population that is in the Hispanic ethnic group. From Grineski et al. (2007).

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 decisions and biodiversity. 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. 2006). 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. 1.14). 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 review*) (Fig. 1.15).

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, *in press*) 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; Fig. 1.16). 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.

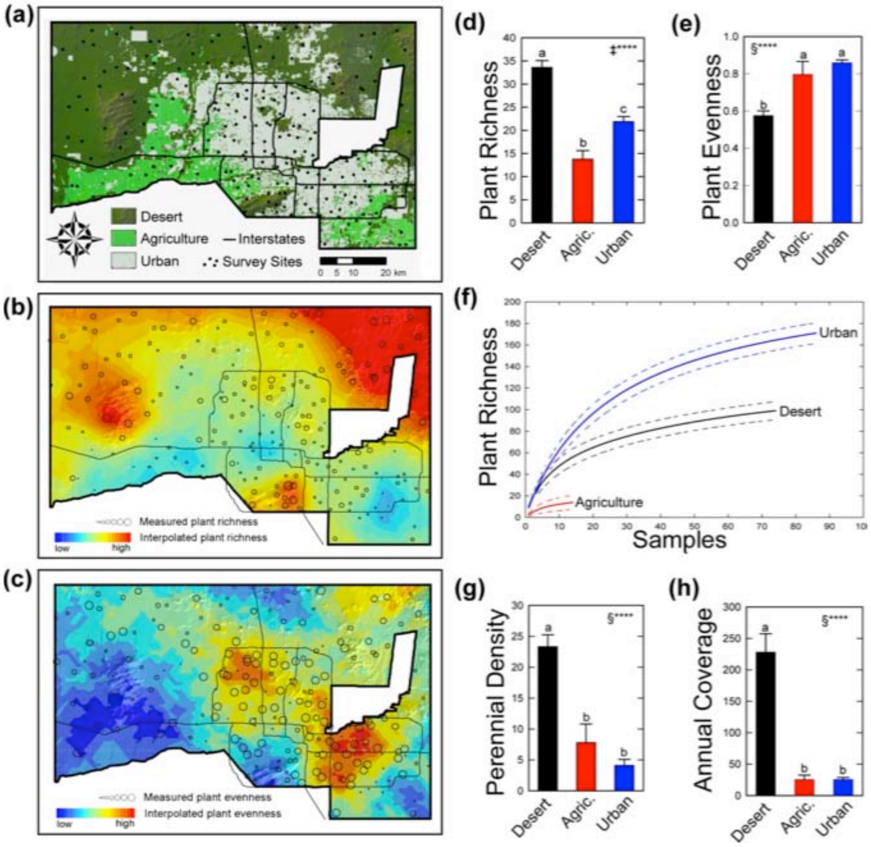


Figure. 1.14. Results from the 2005 Survey200 show strong variation in plant richness (b) and evenness (c) corresponding to coarse-scale land use (a) at the plot scale (d, e), a regionally higher species pool in the urban environment than in desert or agriculture (f) and much higher density of native perennial plants (g) and coverage of native annual plants (h) in desert than in agricultural or urban land uses.

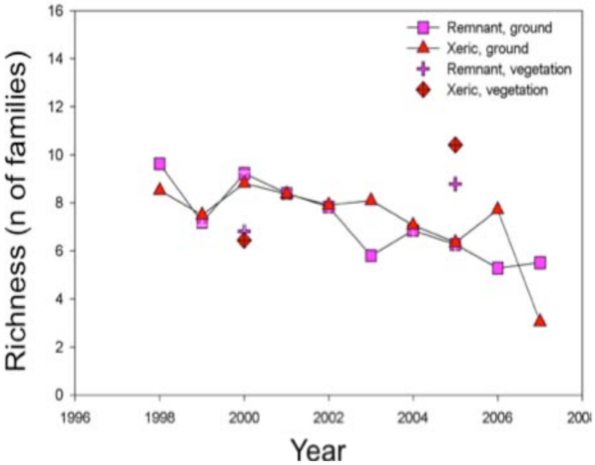


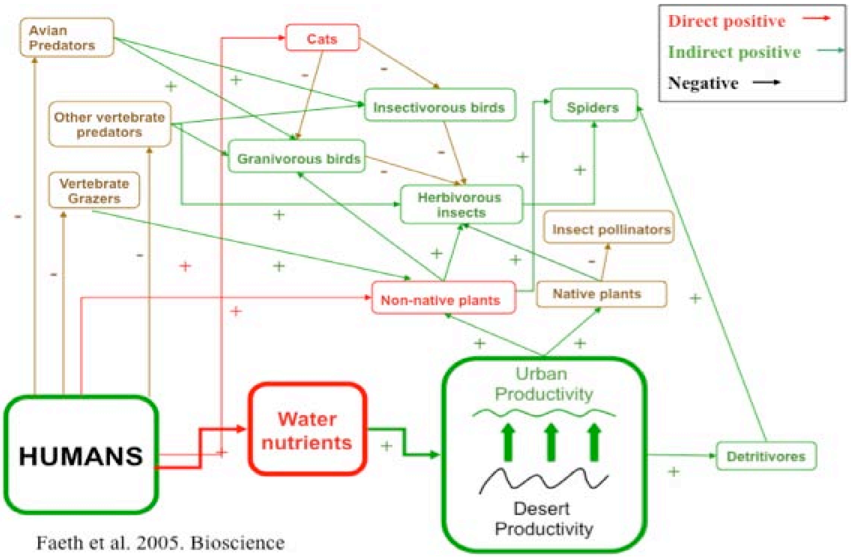
Figure 1.15. Annual variation in diversity of ground living arthropod families from 1998 to 2007, and vegetation-living arthropods in 2000 and 2005, in two habitat types: remnant desert (pink) and xeric residential landscape (red). Error bars are analytical standard deviations.

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.

Network activities: developing a SES agenda. In CAP2, we adopted a slightly modified version of the ISSE conceptual model (Collins et al. 2007) as an expression of our conceptual framework for understanding urban SES (Fig. 2.2). This adoption was no accident; CAP scientists actively participated in developing this framework, particularly its emphasis on human outcomes and human responses/behavior.

Several recent projects, supported through supplements, are direct outgrowths of this framework. CAP scientists Boone and York are leading a five-site comparative study of land fragmentation associated with urban expansion near KNZ, SGS, SEV, JRN, and CAP. This model of "combining forces" to accomplish collaborative network-level research has since been emulated in several other projects involving CAP scientists: MALS (Maps and Locals) and the recently funded cross-site investigation of residential landscapes (CAP, PIE, FCE, BES). CAP Co-Directors Grimm and Redman also were on a team that planned the network-level scenarios of land change work, including workshops at Science Council meetings, the ASM, and at HVR. Grimm, Elser, and Nation co-organized other workshops at the ASM, and Grimm led a ASM workshop to contrast the conceptual frameworks and objectives of the ISSE with the emerging field of sustainability science; a collaborative paper involving many LTER sites that further develops these ideas is in preparation, with CAP scientists Childers and Wiek taking the lead.

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



Faeth et al. 2005. Bioscience

Figure 1.16. Conceptual diagram of the urban food web, showing the direct and indirect positive influences humans exert on various trophic levels. From Faeth et al. 2005.

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.

A. Research dissemination and development of human resources

CAP participants have published >300 journal articles, books, and book chapters since project inception in 1997 (Fig. 1.17). Over 350 individuals have been involved with CAP2, including 101 faculty members, 9 senior project managers, 17 postdoctoral scholars, and 44 technicians, support staff, and K-12 education personnel. Nearly $40 million in leveraged funding (Fig. 1.18) has created a rich interdisciplinary community at Arizona State University (ASU) focused on urbanization and sustainability in central Arizona and beyond.

One hundred 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 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.

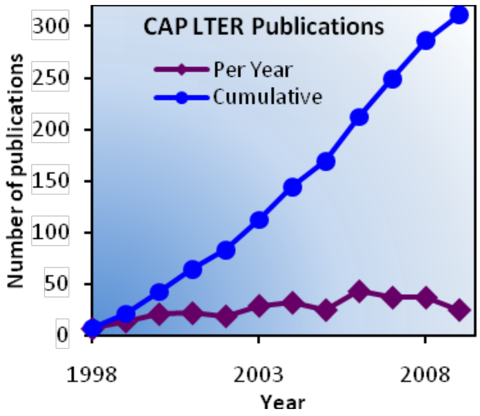


Figure 1.17. Annual and cumulative publications, including articles, books, and book chapters.

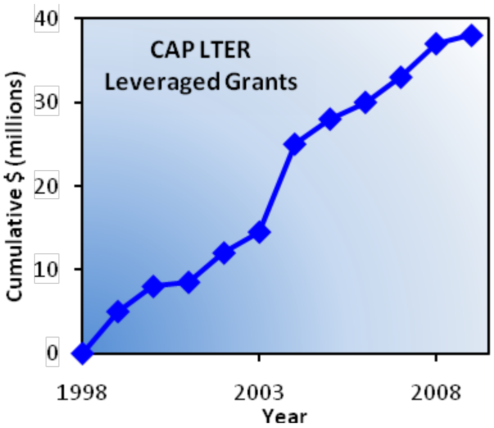


Figure 1.18. Leveraged funding from 1998 to 2009. Cumulative $ in millions.

Part 2 – Proposed Research

II. Introduction and Objectives

Cities are focal points of human population, production, and consumption, including the generation of waste and most of the critical emissions to the atmosphere. They also are “places” of diverse economic and social activities. Harnessed appropriately, the economies of scale offered by cities provide platforms for the transition to a more sustainable world. Cities are complex socioecological systems (SES) that include people *and* ecosystems, as well as their social and ecological contexts. The Central Arizona–Phoenix (CAP) LTER program focuses on these systems, providing the science for their sustainability. We investigate diverse topics within a rapidly urbanizing region at the northern end of the Sonoran Desert in Arizona (Fig. 2.1). CAP includes 26 separate cities surrounded by a shrinking ring of agriculture and the more distal, minimally managed, desert shrubland. In this proposal, we describe continuing and new research conceived within the context of the larger Southwest region, especially the “megapolitan” corridor from Prescott to the Mexican border (Fig. 2.1), and the temporal trajectories of demographic and climate change. The central question to guide this research is:

> ***How do the services provided by evolving urban ecosystems affect human outcomes and behavior, and how does human action (response) alter patterns of ecosystem structure and function and, ultimately, urban sustainability, in a dynamic environment?***

<u>Ecosystem services</u>—provisioning, regulating, and cultural—are defined by the benefits that people derive from ecosystems (MEA 2005). Alterations of ecosystem structure and function may enhance some services and reduce others, sometimes to the point of creating disamenities, and tradeoffs often result (Turner 2009; Bennett et al. 2009). <u>Urban sustainability</u> is the ability of an urban ecosystem to provide comparable levels of services to all its inhabitants, consistent with outcomes that enhance human well being in broad terms, without threatening the delivery of ecosystem services outside the ecosystem or to future generations. These concepts are inherent in our research design and will be explicitly considered in our new synthesis and scenarios project, *Sustainable Futures for Central Arizona.*

Emphasizing the factors contributing to changes in ecosystem services and their roles in the sustainability of urban SES is new to CAP3. We ask three focused questions corresponding to our conceptual framework (Fig. 2.2; presented in Section II):

- **Urban ecosystem services:** How does urbanization change the structure and function of ecosystems and thereby alter the services they provide (i.e., right side of Fig. 2.2)?
- **Human outcomes and actions/responses:** How do people perceive and respond to ecosystem services, how are services distributed, and how do individual and collective behaviors further change ecosystem structure and function (i.e., left side of Fig. 2.2)?
- **Urbanization in a dynamic world:** How does the larger context of biophysical drivers and societal drivers influence the interaction and feedbacks between ecosystems and society (as mediated through ecosystem services) and thereby influence the future of the urban SES (i.e., all of Fig. 2.2)?

Our objective is to direct continuing and new research toward answering these questions. We thus extend our original objectives of advancing theory in ecology to incorporate human and societal drivers and responses, and of enhancing understanding of the structure and function of urban SES.

In addition to these research objectives, our broader goals are: 1) to build understanding and then scenarios that can guide development of sustainable urban SES through collaborations with governmental and nongovernmental partners, other local research groups, and the public; and 2) to incorporate into our research educational opportunities for people of all ages and backgrounds.

III. 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 (e.g., 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 socio-ecological interactions within parts as well as for the whole heterogeneous system (Figs. 2.2, 2.3). 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.

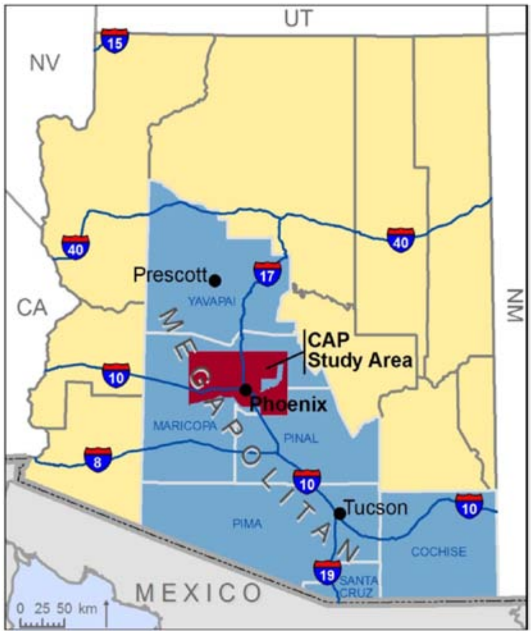


Figure 2.1. Map of Arizona, USA, showing extent of the Sun Corridor Megapolitan (blue shading) and the CAP study area within it (red shading). Gray lines are county boundaries.

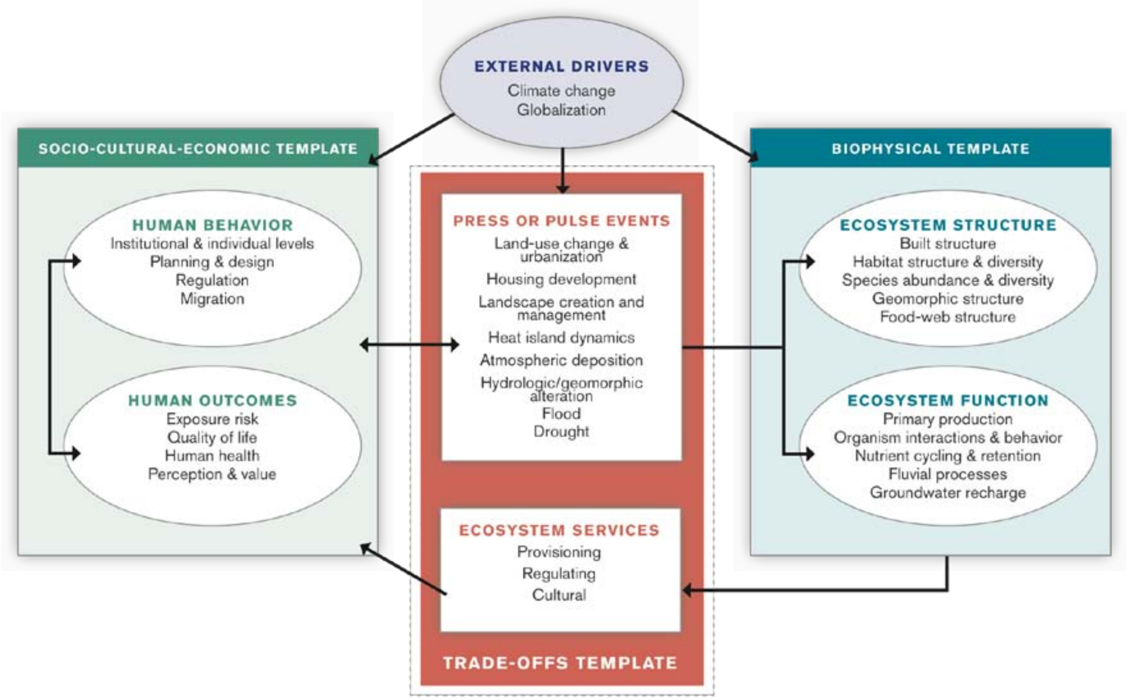


Figure 2.2. In CAP2, we adopted a slightly modified version of the Integrative Science for Soceity and the Environment (ISSE) conceptual model (Collins et al. 2007) as an expression of our conceptual framework for understanding urban socio-ecological systems.

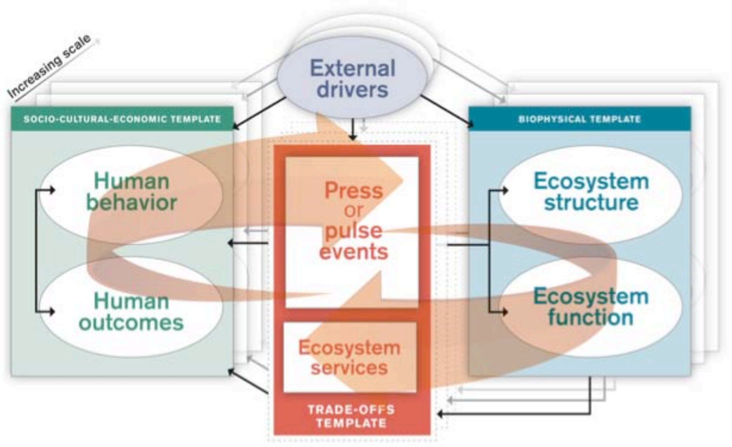


Figure 2.3. The CAP3 conceptual framework can be used to visualize human-environment interactions at multiple scales. These interactions operate continuously in this multiscalar space, as shown by the large circular arrows.

Drivers of long-term change. Global climate change and macroeconomic fluctuations, as examples, are external forces that can drive long-term change (Fig. 2.3, top). CAP has not previously considered these forces, but we will examine climate change as we consider sustainable future scenarios (Section III.C2). Our approach recognizes the interaction between aggregate economic activity, policies to respond to climate change, and changes in local conditions. We will continue to examine internal drivers of change: both press events (e.g., air pollution, irrigation, land conversion) and pulse events (e.g., flood, housing market collapse) (Fig. 2.2).

Space and time scales. Since 1997, our study has centered on a ~6,400-km^2 rectangular area of central Arizona that includes most of metro Phoenix (Fig. 2.1). This geometrically simple area captures CAP's range of landscapes, embedded within a regional matrix of wildlands and other urban centers (Fig. 2.4). We conduct research across the nested hierarchies of landscape scales, ranging from the coarse, urban-agricultural-desert structures to traditional urban land-use categories (e.g., residential, commercial) to differentiated residential-landscaping types (e.g., mesic, oasis, xeric; see Section III.A2). In addition, within the socioeconomic realm, we work with units from household to neighborhood to municipality and, within the desert, plot to site to watershed. Our observational sampling and data-acquisition programs capture event-based or seasonal time steps for fast variables and annual to five-year time steps for slower variables, with many of the latter timed to the US Census.

Ecosystem structures and functions of interest. In addition to the ecosystem components investigated in any LTER, including soil, nutrient stocks, vegetation, and primary and secondary consumers, our urban LTER will focus on the built environment, including urban infrastructure and designed ecosystems, non-native species, and the human population. These components of the SES interact with and control rates of ecosystem processes and functions, such as primary and nutrient cycling, which in turn are the "inputs" to ecosystem services (Fig. 2.3, right).

Ecosystem services. We will address regulating ecosystem services of climate modulation (largely by vegetation), stormwater flow modulation, and air- and water-quality regulation; the provisioning service of urban food production; and the cultural and aesthetic services arising from biodiversity and the sense of place provided by natural desert ecosystems (Fig. 2.3, bottom). Recognizing that designing and building urban areas with one ecosystem service in mind often degrades another (i.e., produces tradeoffs; Fig. 2.3, Bennett et al. 2009; Turner 2009), we will include as many ecosystem services as practical in developing sustainability scenarios and models.

Human outcomes and actions. Building upon CAP2's strong foundation, we will examine: perceptions and economic preferences for services realized from natural microclimate conditions and those modified or managed using energy and water resources; human-health risk due to extreme urban-climate events and exposure to toxic releases, recognizing implications for environmental equity. We will measure human outcomes and actions directly with physical indicators (e.g., incidence of diseases) or indirectly (inferring economic tradeoffs people may make to enhance a valued ecosystem service; for example, from differences in housing price; Klaiber and Smith 2009).

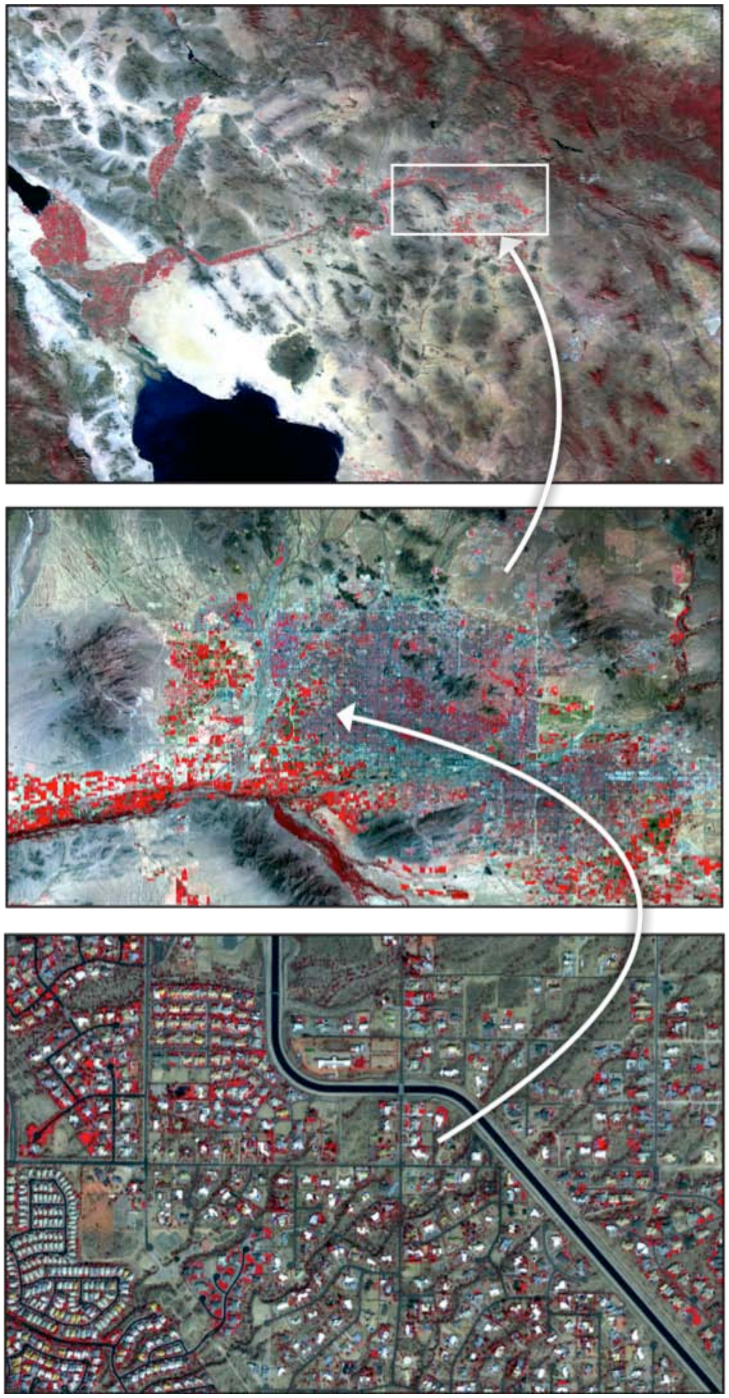


Figure 2.4. Three scales of imagery to be analyzed in CAP3 and associated projects.

A)
Megapolitan scale (250–500 m utilizing MODIS imagery; to be done with other support). False-color composite of MODIS 500-m resolution data displaying channel 2 ((0.841-0.876 μm) in red, channel 1 (0.62-0.67 μm) in green, and channel 4 (0.545-0.565 μm) in blue.

B)
Metropolitan scale (30 m utilizing Landsat-TM and ASTER imagery). False color composite of Landsat-TM 30-m resolution data displaying channel 4 (0.76-0.90 μm) in red, channel 3 (0.63-0.69 μm) in green, and channel 2 (0.52-0.60 μm) in blue. Methods: previous CAP methods (Stefanov et al. 2001), subpixel approaches involving spectral-mixture analysis, and subpixel endmember fraction estimates (Wang 1990; Ji and Jensen 1999).

C)
Parcel scale (1-5 m utilizing Quickbird, IKONOS, and NAIP imagery). Shown is a false color composite of QuickBird 2-m resolution data displaying channel 4 (0.76-0.90 μm) in red, channel 3 (0.63-0.69 μm) in green, and channel 2 (0.52-0.60 μm) in blue. Methods: Object-Based Image Analysis (OBIA) with eCognition software.

When human responses to natural variation in ecosystem services are impossible to observe, stated-preference methods can uncover the choices people might make if given opportunities to change aspects of ecosystem services (Smith 2005).

Evaluation/modeling/ integration/tradeoffs. We will use our conceptual framework to integrate disparate research projects, contextualize our models, and as a starting point for developing scenarios of a sustainable urban SES. We will evaluate the appropriateness of this framework regularly, adjusting components as opportunities arise to improve its generality and applicability.

IV. Continuing and Proposed New Research

Our research is organized to further long-term observations, experiments, analyses of existing data, comparative studies, and modeling, while adding projects in selected areas. Foundational research cuts across all themes and is presented first, followed by theme-based projects and new synthesis and scenario research (Fig. 2.5). We will identify multiple linkages among foundational, thematic, and synthetic work, but note that our efforts to co-locate sites for diverse projects and to base research on common sets of land-use images and classifications will help ensure that connections are used to full advantage. Detailed methods are at http://caplter.asu.edu/data/protocols.

A. Foundational and Crosscutting Long-term Observations and Experiments

A1. ***<u>Characterizing Land Use, Land Cover, and Land Architecture: Parcel to Region</u>***

Land and landscape dynamics are pivotal to understanding and assessing SES, especially in intensively built and managed environments that range from the impervious surfaces of the inner city to the open and wildland interfaces of the suburban/peri-urban fringe. The configuration or "architecture" (i.e., kind, amount, distribution and pattern; Turner 2009) of these lands proves critical to the capacity of the ecosystem to deliver services and to the human outcomes resulting from them. Variations in land architecture, such as suburban-wildland patch sizes, movement corridors, proximity to water sources, or locations of introduced vegetation that change habitats, can determine wildlife abundance (Marzluff and Rodewald 2008). The expansion and design of nearby settlement thereby affect the social preferences exhibited in property values at any particular location. Central to addressing these and other urban SES questions (e.g., heat-health, water-energy use) is the sustained, systematic collection of remotely sensed data coupled with land characterization and classifications, undertaken at different spatiotemporal resolutions.

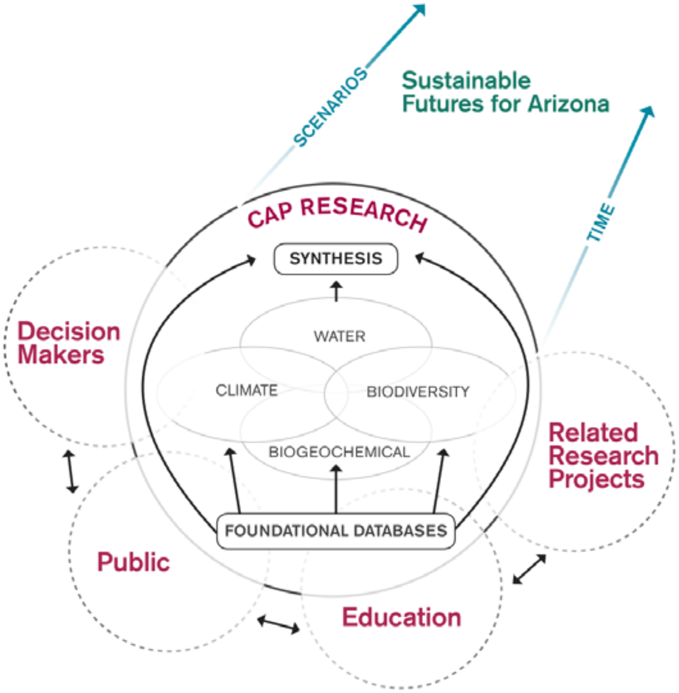


Figure 2.5. Organization of the proposed research. Schematic diagram shows the relationships among CAP research components (foundational datasets, IPA research, and synthesis), collaborating and related research projects and stakeholders, and the envisioning of sustainable futures for central Arizona.

In CAP3, we will launch a systematic remote-sensing and land-classification effort in affiliation with ASU's new Remote Sensing Lab for Sustainability (RSLS). Building on past activities, CAP3 will assess land at two scales of resolution—roughly, the parcel and metropolitan levels—but capable of linking to work on the Central Arizona Megapolitan (non-LTER funds) (Figs. 2.1, 2.4). We will repeat assessments at five-year intervals (in 2010 [CAP2], 2015, 2020,…) to correspond with field surveys and the Census (Sections III.A3,5). In the short run, this new remote-sensing emphasis provides systematic micro- and meso-scale data and land classifications generated for use across most every dimension of CAP research.

Our parcel-scale assessment (Fig. 2.4C) of locales throughout the Phoenix metro area will continue analysis begun in cooperation with the NSF-funded DCDC and Urban Vulnerability to

Climate Change (UVCC) projects. We will expand our analysis to include a full array of the land architectures in the area. These data permit evaluation of subparcel land architecture and provide inputs (such as albedo, land reflectivity, or vegetation cover/phenology) to derive ecosystem services. As a spinoff of this work we continue systematic comparisons to the same imagery assessment in BES, PIE, and FCE research, already underway with LTER supplements.

Analysis at the metro-area scale (Fig. 2.4B) will capture measures that reflect both peak-construction activities preceding the crash of the residential housing market and the steady, multidecadal growth in housing. We will also determine NDVI and albedo and use subpixel analyses to quantify impervious surfaces, soil, and vegetation. The Landsat analysis will link land dynamics from the metro center to the open-wildland interface. Informed by the 1-5-m resolution effort, we will apply a multidimensional land classification and record its changes at five-year intervals.

Finally, we will integrate the CAP database with ongoing activities at ASU through the MODIS data assessment at the regional scale (Fig. 2.4A). This integration will allow us to link the aggregate land dynamics of the Phoenix metro area to land dynamics for the expansive region from the base of Colorado Plateau (Prescott, AZ) to the central Sonoran Desert (Mexican border), one of the fastest growing megapolitan areas in North America (Fig. 2.1; Gammage et al. 2008).

To address the question, *how does land architecture affect the spatial distribution of ecosystem services?,* we will analyze land changes and scalar dynamics (e.g., effects of regional land changes on local ecosystem services). We will derive several input measures for ecosystem services and indirect measures of the effects of spatiotemporal differences in these services for social and economic outcomes. We will couple various sensor bands with models to extract albedo, minimum nighttime and maximum daily temperatures, and others measures of the UHI, and to derive vegetation indices that characterize the climate-modulation service (Section III.B1). Landscape configuration is also central to habitat assessment for biodiversity (Section III.B4), and land configurations may be used to model stormwater runoff and other measures important for water-related ecosystem services (Section III.B2). Finally, we will use the database generated by the land-architecture analysis in our synthesis activity, "*Sustainable Futures for Central Arizona*," to evaluate tradeoffs in ecosystem services under changing population, land architecture, and climate (Section III.C2).

A2. ***NDV Experimental Suburb***

The North Desert Village (NDV), a residential community at ASU's Polytechnic Campus, has been the site of a novel, neighborhood-scale experiment designed to explore how landscaping design influences and is influenced by socioecological processes. Four residential landscape designs, established in mini-neighborhoods of six households each, recreate the prevailing residential landscape types found throughout our study area (Martin et al. 2003; Fig. 2.6). These landscape designs include: *mesic* (a mix of exotic, high-water-use vegetation and turf grass), *oasis* (a mix of drip-watered, high- and low-water-use plants and sprinkler-irrigated turf grass), *xeric* (individually watered, low-water-use exotic and native plants), and *native* (native desert plants receiving no supplemental water). Six additional households are monitored as a no-plant, no-water control.

Research began in Fall 2003 with pre-treatment baseline surveys of soil, mycorrhizae, vegetation biomass, ground arthropods, birds, and human occupants (see Part 1). Micrometeorological stations installed in each mini-neighborhood monitor soil and atmospheric conditions (Fig. 2.7). Clearly, the stark contrast in ecological conditions and processes among these landscape types affects water use, plant and animal diversity, and quality of life. The costs and benefits associated with residential landscape styles for the greater community are poorly understood, however; a holistic knowledge of the impact of landscaping decisions on overall ecosystem function is essential to ensure that residential landscapes are conceived and managed in a sustainable manner (Harrison et al. 1987).

Figure 2.6. Photos of experimental residential landscapes of the NDV. From top: mesic, oasis, xeric, and native desert vegetation types. Photos by Chris Martin.

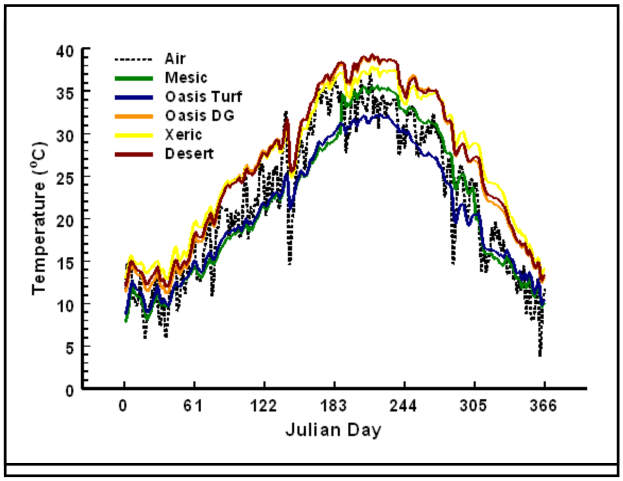


Figure 2.7. Mean irrigation volume for maintaining three residential landscapes that have supplemental water at NDV (top), and resulting annual pattern of near-surface soil temperatures in the four landscape types.

In CAP3, we will capitalize on this unprecedented experiment to advance understanding of sustainable development. Armed with an ecosystem-services approach, we will ask: ***what is a sustainable residential landscape in the arid Southwest?*** We will examine costs and ecosystem services (microclimate regulation, water use, and carbon sequestration) associated with each landscape type. We will overlay results with high-resolution, remotely sensed imagery (Section III.A1, Fig. 2.4c), allowing us to associate ecosystem services and surface characteristics, extend results across the metro area, and incorporate them into our land-architecture model (Section III.C2). In addition, interactions with NDV residents will help to elucidate attitudes and perceptions associated with landscape types and ecosystems services and their tradeoffs. It may not be possible to increase (or even maintain) all ecosystem services associated with these landscapes.

As a result, tradeoffs are inevitable. We will expand resident surveys to ask about perceptions of additional ecosystem services like carbon sequestration, soil formation, and soil retention (MEA 2005). Further, we will add a micrometeorological station in the control mini-neighborhood to assess conditions in a sparse residential landscape receiving few material or energy inputs. We will apply model estimates of turf-grass contributions to NPP to assess differences in total NPP among treatments, and evaluate long-term effects of treatments on soil and subsoil development. Finally, we will use NDV microclimate and ecological data to develop parameters for an urban microclimate model, ENVI-met (see Section III.B1).

A3. ***Survey200***

Survey200 is a central CAP research component used to track SES change over time. This extensive field survey provides a snapshot of broad-scale variations in key ecological variables across the region (Fig. 2.8), repeated every five years at ~200 locations. The survey, conducted in 2000 and 2005, will be repeated in Spring 2010 and 2015 and will include core measurements, such as:

- Plants identified to species (2005) or genus (2000)
- Plant-size measurements for biovolume calculations
- Georeferenced mapping of built and vegetation structures
- Soil coring for physicochemical and metal analyses, microbial communities, and black carbon (bC) analyses (upper 2 cm; new)
- Insect sweep-net sampling

Results from both the 2000 and 2005 surveys have been reported in many CAP publications (Hope et al. 2003, 2005, 2006; Oleson et al. 2006; Stuart et al. 2006; Zhu et al. 2006; Dugan et al. 2007; Walker et al. 2009). We have developed innovative statistical methods, including hierarchical Bayesian modeling (Kaye et al. 2008; Majumdar et al. 2008, *in press, in review*) to handle data and assess patterns and controls of multiple soil or plant variables for the region. Land-use and demographic data (see Sections III.A1 and 5, respectively) are used to create a spatially explicit map of ecological properties and their controls. Beginning in 2010 for residential land uses, we will expand plots that were formerly 30x30 m in size, centered on an exact point, to incorporate the largest "parcel" that impinges on the 30x30 m plot (Fig. 2.8). Data for both pieces (parcel and square plot) will be collected and recorded separately. These data offer opportunities for groundtruthing new parcel-level, high-resolution land classifications and will add a new set of sites to our long-term survey program corresponding to the household scale of analysis.

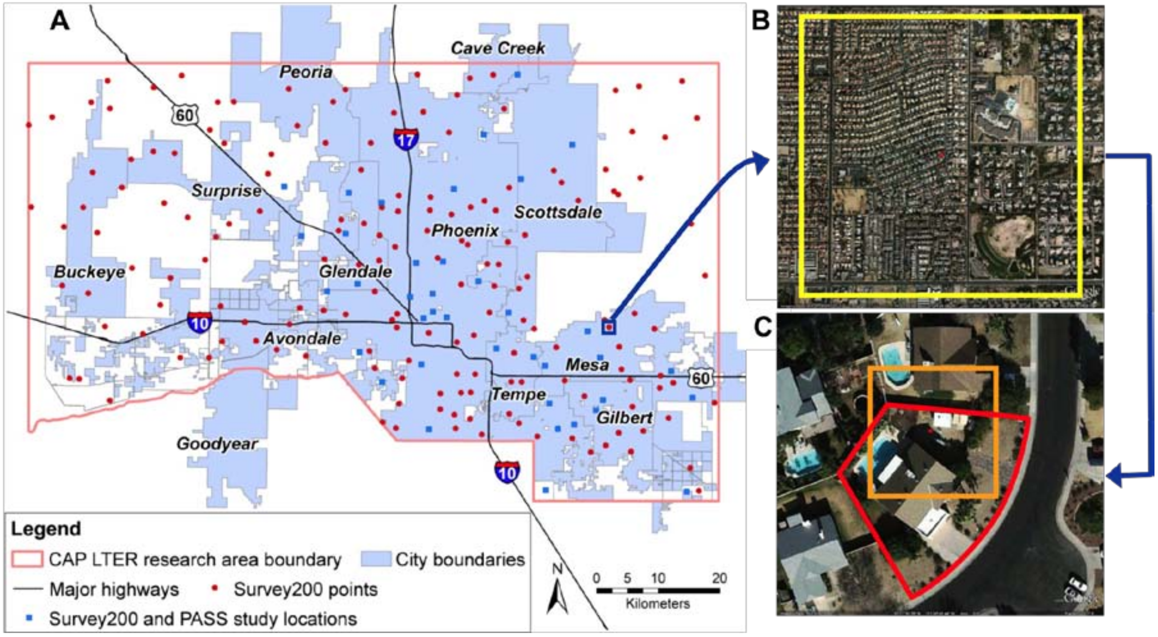


Figure 2.8. Metro Phoenix showing the boundaries of the Survey200 study area (A, red outline). Points indicate the 200 survey sites; blue points indicate survey points located in PASS neighborhoods. At a "neighborhood" scale (B, shown as 1 mi^2 of residential land use), survey200 sites are within desert, residential, commercial/ industrial, or industrial land uses. In 2000 and 2005, survey sites themselves were 30x30 m plots centered on each point (orange outline in C), and beginning in 2010 in residential land uses, entire parcels will also be sampled by adding the additional land surface within the largest parcel that impinges on the 30x30 m plot (red outline in C).

A4. ***Phoenix Area Social Survey (PASS)***

PASS, our long-term monitoring program of social attitudes and behavior, parallels the Survey200 and is a collaborative effort between CAP and DCDC. Following a pilot household survey in 2001-2002, an expanded team of social and biophysical scientists conducted the second wave of PASS in 2006, studying 808 randomly selected households in 40 neighborhoods co-located with Survey 200 field sites. Each survey location was georeferenced to enable us to link social and biophysical contextual data with responses. PASS survey questions engage human perceptions, values, and behaviors on the quality of community life and the environmental domains that CAP and DCDC emphasize, such as: water supply and conservation; land use, preservation, and growth management; air quality and transportation; and climate change and the UHI.

PASS is an important vehicle for addressing questions about: 1) how human communities form, adapt, and function in a rapidly urbanizing region; 2) how human knowledge, perceptions, and values affect behaviors that transform an ecosystem into an urban landscape; 3) how spatial variations in ecosystem characteristics relate to social-class inequalities and cultural differences; and 4) how changes in social, economic, and environmental systems affect the quality of life and vulnerability to environmental hazards for diverse human populations.

A5. ***Economic and Census Data Analysis***

The primary challenge in analyzing economic and social statistics is to exploit the rich spatial detail to understand how the level and composition of human activities are affected by ecosystems, defined within consistent scales. The US decennial Census is a fundamental and rich social-science dataset, providing comprehensive data on population, housing, and economic characteristics at a variety of geographic scales. For research in metropolitan areas, the census tract and the subset of census-block groups offer one basis for defining neighborhoods (Harlan et al. 2007). All data are available at the census-tract level (4,000-8,000 persons) and nearly all variables are released at the census block-group level (1,500-2,500 persons). Over the past decade, the Census has used the annual American Community Survey to supplement its estimates of population, housing, and economic characteristics.

CAP LTER maintains a geodatabase of census data in two formats: as attributes of digital census boundaries (GIS) and as flat files on our server. Although census variables and geographies change over time, historic census data are used to understand the socioeconomic dynamics of cities. CAP maintains census data for the study area at the census-tract level. Maricopa and Pinal county census data (1880-present) were combined with data for all LTER sites with NSF and USDA Forest Service supplemental awards and are part of the TRENDS database housed at the LTER Network Office.

Basic population counts are available at the census-block level, but other variables are suppressed to maintain confidentiality. We can tap into other sources to discover individual characteristics. PASS (Section III.A4) will be important in filling this gap. Because households are critical management units in urban ecosystems, we will continue to collect updated geodatabases from the Maricopa County tax assessor. These include parcel boundaries and attributes on housing and land characteristics along with assessed value and sales prices. We will couple parcel attributes to landscape metrics through the proposed object-oriented analysis (Section III.A1; Fig. 2.5) and use them to estimate how measures for the amount and changes in ecosystem services at the parcel and neighborhood scale influence the levels and changes in sales prices over space and time.

These types of hedonic analyses allow us to estimate the economic tradeoffs for increases in ecosystem services. The analyses assume that households understand how the ecosystem services they experience change over time and space. To link records on these housing transactions and indexes of ecosystem services to PASS survey data provides a unique opportunity to assess the consistency in people's understanding of the spatiotemporal differences in these services with the direct and indirect measures taken from monitored records (Abbott and Klaiber *in review*; Klaiber and Smith 2009; Phaneuf et al. 2008).

B. Integrative Project Areas

To fully integrate social and ecological components, we organize our research under four integrative project areas (IPAs) that represent the intersection of ecological with social-science core areas (Redman et al. 2004). The former Land-Use and Land-Cover Change IPA has been added to our foundational, crosscutting research portfolio (Section III.A.1) and as a new synthesis activity (Section III.C2). The other four IPAs remain, although redefined to better reflect their emphases. CAP3 will add explicit consideration of ecosystem services and human well being to each IPAs. We weave these concepts, and the work we will do to uncover them, throughout the research proposed in this section.

B1. ***Climate, Ecosystems, and People***

The goal of this IPA is to understand interactions among urban and urban–hinterland climate, ecosystems, and social systems. Our work will advance basic science while facilitating decision making about the mitigation of—and adaptations to—climate change in arid SES. CAP3 will create a local "geography" of climate that incorporates demands on resources (landscape, water, energy), stakeholder perceptions, economic indicators (economic tradeoffs or marginal willingness to pay for changes in observable indexes for ecosystem services), human vulnerability indicators (heat-related comfort, morbidity, and mortality), and models of future climate and land-system interactions.

Large-scale atmospheric forcing modified by natural landscape features (terrain) and characteristics of the urban land surface (building and vegetation distribution, irrigation) influence climate in the CAP region. Climate change, therefore, will play out through the interaction of global drivers with regional presses and pulses (see Section II, Fig. 2.2). Global climate change is likely the main example of an external driver, while land-use and land-cover changes, driven largely by economic growth or recession, represent the main pulse events for regional climate change. Three questions frame the Climate IPA:

Question 1: How does local climate influence ecosystem function and structure and consequently the provision or alteration of microclimate-related ecosystem services?

Our research has shown how the spatiotemporal dimensions of urban development and land management dictate the magnitude and diversity of primary production, urban heating and local microclimate. Our research trajectory will enable us to estimate measures for the physical and economic tradeoffs associated with changes in microclimate-related ecosystem services. These measures will comprise spatially explicit and multiscaled physical, social, and economic resource inputs required to sustain ecosystem structure and function. *We hypothesize that people modify the structure of residential landscapes to enhance microclimate-related ecosystem services and that, in turn, these modifications of temperature regulation have major consequences for other ecosystem services.* We will test this hypothesis by 1) fine-scale mapping of stored carbon, accumulated biomass, and vegetation biovolume; 2) using the NDV experiment to quantify the differential effects of landscape structure on microclimate and surface energy balance as a function of supplemental water delivery; 3) continuing our development of models to relate canopy cover to biomass, stored carbon, and microclimate; and 4) applying models such as ENVI-met (Bruse and Fleer 1998) and LUMPS (Gober et al. 2010) to simulate microclimates at high resolution, to gain an understanding of how modification of landscape-ecosystem structure affects microclimate.

Work Plan for Question 1: We will use data from past and future 200-point surveys (Section III.A3) to analyze accumulated biomass and biovolume and their change over time. We will use these data to validate biomass models that support other IPA research on the urban carbon cycle and ecosystem productivity. We will carry out high-resolution biomass mapping for the entire region and validate with remotely sensed vegetation indexes (e.g., NDVI) and 200-point survey data. We will continue to use phenological data as indirect measures of local climate change (Fig. 1.5).

The managed landscapes in the NDV experiment are maturing (Section III.A2). We will take advantage of this trajectory by continuing analyses on the effects of landscape management strategies on microclimate and surface energy balance. We will continue to measure microclimate, NPP, residential water and electricity use, and resident preferences. We will expand our neighborhood-scale analyses by measuring turbulent heat and CO_2 flux data in a neighborhood in West Phoenix, where we recently installed a permanent flux tower. We will apply the ENVI-met model to simulate microclimates with 1-m spatial resolution for the tower and NDV neighborhoods to better understand local microclimatic dynamics.

Question 2: What are the public perceptions of local climate and associated ecosystem services, and what tradeoffs would people make to enhance or avoid declines in the levels of these services?

We will continue investigating public perceptions of ecosystem services related to climate using an economic-tradeoffs approach. Ruddell et al. (2010) found that respondents to the 2006 PASS (Section III.A.4) were aware of temperature differences in their neighborhoods relative to others and that their perceptions of hot weather closely tracked measured differences in local temperatures. Respondents would be willing to pay significantly more for homes comparable to those in which they lived, if they were located in neighborhoods with 5-10° cooler conditions (Harlan et al. 2007). Klaiber and Smith (2009) confirmed these findings using records for the sales prices of nearly a million homes sold between 1995-2005 matched to monitored records for the minimum July temperatures in the homes' neighborhoods, after controlling for house, parcel, and sociodemographic characteristics of neighborhoods in Maricopa County. *Our hypothesis is that individuals and households perceive temperature differences among locations and that locations with lower summertime maximum and nighttime minimum temperatures hold higher economic value.* To test this hypothesis, we will expand studies of how public perceptions and economic preferences for climate-derived amenities or disamenities vary seasonally and among social groups.

Work Plan for Question 2: We will use our PASS 2011 questionnaire to ask stated-choice questions in conjunction with market analyses of residential home sales and residential water use (e.g., Klaiber et al. 2009). PASS 2006 provided a baseline for understanding perceived climate at the regional and neighborhood scales (e.g., Ruddell et al. 2010). Results identified significant differences in perceived regional and neighborhood temperatures among the 40 neighborhoods in the study area in Summer 2005. It also is feasible to use stated-choice survey questions to recover measures of the economic tradeoffs for changes in readily perceived and recognized ecosystem services (Smith 2005). PASS 2011 results will allow us to continue measuring and testing these relationships and investigate temporal changes in perceptions.

We will conduct economic-tradeoff analysis on home-sales data, by time and location, throughout the study area. Our analysis of home sales in Maricopa County from 1990–2006 showed sufficient variation in location attributes to separate the effects of other landscape characteristics, such as mesic vs. xeric conditions, while controlling for house characteristics (Klaiber and Smith 2009). CAP3 will evaluate the consistency of perceptions with observed measures of vegetative cover and temperatures and analyze seasonal differences in microclimate for diverse social groups.

Question 3: How does a spatially heterogeneous pattern of regional temperatures affect the distribution of ecosystem services and create health disparities among different social groups?

Jenerette et al. (2007) found that socioeconomic status of neighborhoods was the most important social predictor of urban vegetation and thereby indirectly influenced the spatial distribution of temperatures. In the year 2000, lower-income, inner-city neighborhoods, and selected middle-income neighborhoods on the urban fringe were exposed to higher summer temperatures for longer periods of time and thus had higher heat-stress index scores owing either to their location within the UHI or to their land-cover characteristics (Harlan et al. 2006). In CAP3, we will continue investigations of the biophysical and social dimensions of local climate change as they affect residents of central Arizona, both in tandem with the land architecture analyses described below (Section III.C2) and in collaboration with the NSF-funded UVCC project. We will expand our analyses of regional spatial temperature patterns and their impacts on people through the delivery of ecosystem services (e.g., temperature regulation), as well as heat stress, heat-related illness and death, and other health outcomes. *We hypothesize that heterogeneous microclimates within the Phoenix metropolitan region, which correspond to locational and land-cover factors, explain variation in health vulnerability among neighborhoods and social groups*.

Work Plan for Question 3: We will use new remotely sensed data and analytical tools at 1- to 5-m resolution (e.g., OBIA; Fig. 2.4) to relate residential land covers to population characteristics in select areas (Myint and Okin 2009). We are also compiling georeferenced data on heat-related hospitalizations and deaths (2000–2008) with ASU's Center for Health Information and Research, have access to georeferenced heat-related 911 calls, and will use these data to relate health outcomes to land cover, temperature, and sociodemographic profiles in strategic locations, such PASS residential neighborhoods. We will use spatial (ENVI-met) and point (OUTCOMES) models (Brown and Gillespie 1995; Heisler and Wang 2002) of urban microclimate and human comfort to estimate and compare air temperature and human heat stress indices at the same locations. Ultimately, we will produce metrics that quantify tradeoffs between temperature, water use, and human heat stress at household and neighborhood scales.

We will analyze Census data (2000, 2010), PASS data (2006, 2011), and surveys of low-income, Spanish-speaking households in South Phoenix to produce such indicators as self-reported heat-related illnesses and mechanisms that families of different socioeconomic and cultural backgrounds use to cope with extremely hot weather, information that helps us to assess vulnerability. We will examine how people report using water to mitigate the effects of heat and heat stress in and around their homes.

We will engage government agencies, (e.g., National Weather Service in Phoenix, Maricopa County Department of Public Health) as well as nonprofits and neighborhood associations in structured interactions to: 1) share research findings about climate, people, and health; 2) construct collaborative science/policy models of local responses to heat vulnerability to improve the heat-adaptive capacities of vulnerable neighborhoods. We will undertake these stakeholder-outreach activities in close collaboration with DCDC and ASU's Decision Theater.

B2. ***Water Dynamics in a Desert City***

The goal for this IPA is to understand how the management of urban water systems in cities affects feedbacks and tradeoffs among water-related ecosystem services, and how climate change and its uncertainty affect these tradeoffs. This goal encompasses all key components, interactions, and feedbacks of the CAP3 SES (Fig. 2.2). We define the "urban water system" as the human capital and technology that provide water and manage wastewater and stormwater in cities. Management occurs at all scales, from regional water management to choices made at the individual level.

In arid landscapes, water is typically found around a few large rivers with clearly defined, ecologically productive riparian areas. Cities in arid environments display a similar "oasis" characteristic as humans re-allocate water, and these cities are often located along rivers. Our Water IPA will focus on what we define as a "riparianization" of desert ecosystems, as urbanization redistributes water more extensively and evenly across the landscape, compared with the pre-human situation (Fig. 2.9). This concept may be more broadly generalized as the "arboreolization" of grassland ecosystems by urbanization. This redistribution of water may be the single-most important effect of urbanization in arid lands. It is a product of the conversion of natural hydrology to man-made hydrology via modification (local changes), procurement (regional changes), and management (temporal changes; Grimm et al. 2008a; Redman and Kinzig 2008). The implications of this process are ecological (higher productivity), climatic (buffering of the UHI), hydrologic (water becomes much more available and pollutants are redistributed), social (numerous), and economic (numerous), particularly relative to the desert that the city is replacing. Riparianization has important ramifications for the "water footprint" of an aridland city (e.g., Jenerette et al. 2006), as it clearly affects the watersheds that have been modified and/or de-watered to provide water to the city.

Figure 2.9. Riparianization in Scottsdale, AZ. In the foreground is the Indian Bend Wash floodway, but expansive areas of green vegetation can be seen far beyond the channel owing to redistribution of water onto residential and commercial landscapes.

Question 1: How does urbanization alter the hydrologic connectivity of aridland ecosystems and modify watershed boundaries and configurations, and what are the consequences for ecosystem services associated with stormwater?

Understanding riparianization requires quantifying how hydrologic networks and connectivity change as aridlands are urbanized and water is redistributed across the landscape. Fine-scale heterogeneity of soil/vegetation characteristics and broad-scale heterogeneity controlled by geomorphology (McAuliffe 1994; Wondzell et al. 1996) typifies natural desert ecosystems. The structure of urban ecosystems is greatly modified, however, with multiple processes exerting control over spatial scales and distribution of hydrologically relevant land-surface properties (Roach et al. 2008). During urbanization, humans alter topography, construct stormwater management infrastructure, and modify drainage patterns with roads, canals, berms, impoundments, and retention basins—all of which dramatically affect watershed characteristics. To understand the geometric (topological) differences between natural and man-made systems, it is also important to quantify the urban hydrological landscape in a spatial framework. An important component of the urban hydrologic landscape is the stormwater network, which serves to: 1) reduce risk from flooding and dispose of stormwater and 2) create parks and other recreational/ecological areas that increase property values and services to society. *We hypothesize that: 1) urbanization modifies watershed boundaries and configurations, altering the hydrologic connectivity of aridland ecosystems; and 2) the spatial configuration of natural vs. urban channels affects the presence of biogeochemical hotspots and processing rates in active areas.*

Work Plan for Question 1: We will quantify the land cover and spatial distribution of hydrologically relevant components (impervious areas, stormwater retention basins, landscaping classes) of key drainages representing varying levels of urbanization using aerial photographs and municipal-development plans. We will also quantify watershed modifications by delineating the lateral connectivity network from digital elevation models, including LIDAR, as well as stormwater-drainage infrastructure plans. We will describe changes in hydrologic connectivity by deriving terrain and network metrics (drainage density, channel sinuosity, Horton order statistics). Hydrologic connectivity will be superimposed on open (park) spaces to quantify the degree to which the urban stormwater network influences ecosystem services. Collaborating with a NSF-funded urban stormwater project, we will also determine how alterations of connectivity and channel form influence the transport and retention of sediment, nitrogen, phosphorus, and organic pollutants.

Question 2: Can riparianization be accomplished in a sustainable manner—where water use and alteration of the natural hydrologic system are minimized while also retaining related ecosystem services—during urbanization?

The best way to understand how urbanization modifies natural hydrologic processes in any ecosystem is to experimentally track the conversion of natural hydrology into managed hydrology by development (e.g., Graf 1975; Roach et al. 2008; Redman and Kinzig 2008). We will follow changes to a desert hydrologic system before, during, and after its urbanization and work with the developer and contractors to experimentally test different designs and stormwater management approaches. We have selected several future development sites in the Phoenix valley as potential locations for this experiment and are in contact with relevant developers. The dramatic slowing of urban sprawl by the economic downturn has afforded us considerable flexibility in solidifying these details. Hydrologic and scenario-based modeling will be critical to this experiment and to the work plan.

Work Plan for Question 2: Our approach will be similar to a before-after-control-impact (BACI) design. Parameters to be quantified include land cover and change, topography, flow rates in natural drainages, modification of drainage networks by roads, structures, and stormwater systems, ecohydrologic and biogeochemical processing, sediment and pollutant transport, soil moisture, and water distribution across the landscape. Modeling will be an important component of this experiment and will help in the monitoring design and field deployments. For the desert system, we will parameterize the tRIBS distributed model (Vivoni et al. 2007, 2009) under natural conditions and use the model to simulate streamflow, land-atmosphere fluxes, soil moisture, and water retention, which can be tested against available data. We will then use tRIBS to create "virtual developments" that simulate urbanization scenarios and their effects on the hydrologic response. The model can also be tested in the actual post-development case, providing a tool that can be implemented in other rapidly urbanizing settings. We will conduct this planning/ simulation/scenario effort in ASU's Decision Theater, in close association with DCDC, and it will comprise part of our broader scenario work.

Question 3: How can we combine the virtual water concept with tradeoffs models (economic and otherwise) to quantify feedbacks among water-related ecosystem services?

Water enters into the production of a range of urban ecosystem services, particularly in aridland cities. For many of these services, there are important tradeoffs among alternative pathways of production and substitution in water consumption. For example, air conditioning may substitute for the cooling effect of irrigated vegetation, but the former embodies water in the production of electricity. Understanding such physical tradeoffs among production and consumption substitutions of water-related ecosystem services, at different spatial and temporal scales, is necessary for sustainable water use. To analyze these choices, we will use a holistic understanding of the water embodied in the production of these services and the associated economic opportunity costs. The concept of "virtual water" has been used as a common unit of accounting to compare relative water use across locations and goods (Allan 1993; Hoekstra and Hung 2002; Chapagain and Orr 2009). We will use a modified version of this concept, termed as "localized virtual water" (LVW, Ruddell 2009), which addresses some of the limitations of virtual water when applied to analyze physical tradeoffs and derive policy implications. Localized virtual water is distinguished from global (standard) virtual water by accounting for the origin of water withdrawals and embodied water inputs (whether local or imported), and for the recycling of water within a local control volume (Fig. 2.10). Virtual water content is a function of the virtual water content of locally produced inputs (LVW_{IN}), the raw water input from withdrawals from the local stock (w^1_{IN}), and the volume of water recycled back to the local water stock (R^1_{OUT}) as:

$$LVW_{OUT} = LVW^1_{IN} + w^1_{IN} - R^1_{OUT}$$

Using LVW to measure water use embedded in the production of a good (LVW_{OUT}) can improve the accuracy of studies of the production function for the ecosystem services (Nelson et al. 2009).

<u>Work Plan for Question 3</u>: We will collaborate with researchers at DCDC to use the LVW metric for specific applications, including urban agriculture, residential landscape design (Larson et al. 2009a), UHI mitigation (Guhathakurta and Gober 2007; Gober et al. 2010), open space (Abbott and Klaiber *in review*), landscape amenities (Klaiber and Smith 2009), and electricity production for indoor climate control. For these applications, we will construct a coupled economic and water-resource model (Fig. 2.10) to assess policies for more sustainable allocation of water. Our goal is to better understand the connections between water-use practices, the value of water-related ecosystem services, and the spatiotemporal scales at which water is managed.

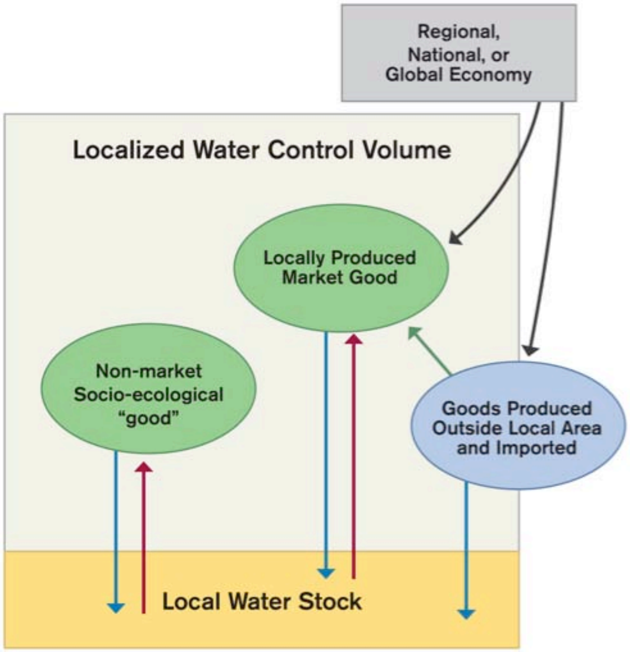


Figure 2.10. Schematic diagram of a coupled economic and water-resource model to be used in the virtual water project.

B3. ***<u>Biogeochemical Patterns, Processes, and Human Outcomes</u>***

Research in this IPA will continue to focus on understanding how and why urban biogeochemical cycles differ from those of undeveloped ecosystems (e.g., Kaye et al. 2006) and the consequences of those altered cycles and distribution patterns for human well-being (e.g., Grineski et al. 2007). Human manipulation of biogeochemical cycles through agriculture and energy use has supported societal advances that have increased the carrying capacity of Earth, including the green revolution and modern industrial technology. However, these advances have also led to major environmental problems, from local-to-global scales (Grimm et al. 2008b), threatening biodiversity, ecosystem integrity, and quality of life. Ecosystem services associated with biogeochemical cycles therefore can be beneficial or harmful. In CAP3, we will consider urban stoichiometry (relative abundance of C, N, P, and salts), add a focus on fluxes at the household scale, expand our consideration of materials to include novel organic compounds, and explicitly consider the drivers and consequences of spatial distributions of these materials. The organization of the research is multiscaled, from the local/plot scale (individual households/yards, agricultural or desert plots) to the regional SES.

Question 1: How do urban elemental cycles at multiple scales differ qualitatively and quantitatively from those of nonurban ecosystems?

Ongoing research in this IPA quantifies metro-scale, whole-system budgets for N, C, and salts, revealing urban ecosystems to be high-throughput, heavily loaded ecosystems. Human imports dominate material inputs for C and N, and waste exports (wastewater-borne materials and gaseous wastes, such as CO_2 and NO_x) are transferred to recipient systems via water and wind vectors (see research under Question 2). Thus, we have advanced our understanding of the changes in individual cycles attending urbanization, but we have not yet determined how human activity alters those cycles differentially, and thus changes stoichiometry. *We hypothesize that human activity alters stoichiometry between imports and exports due to differential retention and storage of materials.*

To date, we have completed mass balances at the coarse metro scale (e.g., Baker et al. 2001). To evaluate potential future changes (and possible solutions) in material cycles as urbanization proceeds, we need a more mechanistic understanding at the homeowner scale. A focus at that scale allows us to develop scenarios for sustainable urban biogeochemistry and to communicate best practices for reducing pollution. For example, turf lawns often receive more chemical inputs per land area than intensive agriculture (NRC 1980) and are the largest irrigated crop in the US (Milesi et al. 2005)—yet little effort is directed toward improving landscape-management practices. Factors explaining homeowner decisions (e.g., on lawn maintenance) and their ecological outcomes are relatively unexplored. Combined with a more comprehensive, cross-site study of residential landscapes, we will initiate mass-balance studies to test the hypothesis that *impacts of human-enhanced material cycling can be reduced through nutrient management at the household scale.*

<u>Work Plan for Question 1</u>: We will develop updates for metro-scale mass balances of C, N, and P, allowing us to evaluate changes due to increased urbanization or, potentially, changes in per-capita resource use. We will examine how human activity alters the stoichiometry of nutrient cycles by comparing C, N, and P export fluxes between urban and nonurban systems.

To construct household-scale budgets, we will modify the “household flux calculator” (HFC) developed by CDR LTER colleagues for St Paul, MN neighborhoods (Baker et al. 2007) to build C, N, and P budgets for PASS neighborhoods, allowing us to relate differences among these distinct neighborhoods to socioeconomic variables (from PASS and other databases). We will add questions to the PASS survey (see Section III.A.4) to gather the data needed to calculate budgets and will implement an education/ outreach activity using the HFC for local schools (see Section V).

Question 2: What are the fates of elevated material inputs, and how do they affect ecosystem processes and the delivery of ecosystem services in recipient systems?

Our biogeochemical conceptual model (Fig. 2.11) identifies four reactive ecosystem compartments (atmosphere, land, surface water, groundwater), any of which may be a source, a recipient system, or a transporting/transforming system for a particular material flux. Toxins and pollutants may become concentrated in urban recipient systems to generate biogeochemical “riskscapes” for urban inhabitants, and nutrients may be transported to low-productivity desert recipient systems where they have a fertilization effect. Ongoing studies of the fates of material fluxes include: 1) desert responses to deposition, 2) soil-nutrient distributions; 3) air quality; and 4) water quality.

<u>*Ecosystem response to the urban atmosphere*</u>: Native ecosystems within and surrounding cities show human impacts on ecological functioning, as they have experienced long-term atmospheric changes at levels and combinations that mimic future global scenarios, including warmer temperatures and enrichment of CO_2, O_3, and reactive N (Carreiro and Tripler 2005; Shen et al. 2008). We have been studying the atmospheric-fertilization effects of urban-derived N and organic C on primary production of the surrounding desert ecosystem (in part with leveraged funding). When ample water is available, we have discovered enriched soil C and N pools and enhanced growth of fast-response biota such as annual plants. Consistent with this finding, long-

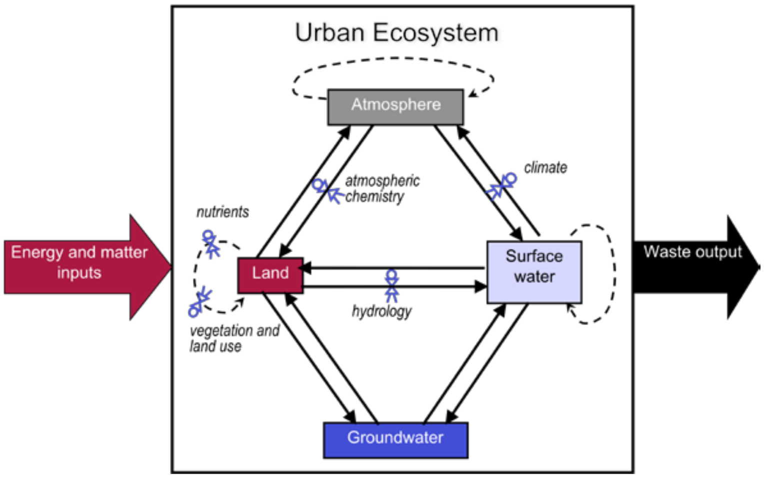


Figure 2.11. Model showing major compartments of the biogeochemical cycles. After Kaye et al. 2006.

term fertilization experiments show N limitation and secondary P limitation, but only in wet years. CAP3 will continue these long-term experiments and measurements along a rural-urban gradient (see Fig. 1.9).

Soil nutrient and metal distributions: Human-mediated deposition inputs, along with land-use legacies, govern material content of soils (see Section II), but soils are less subject to transport than other systems. Using Survey200 (Section III.A3) to quantify spatial variation in soil chemistry, we have found support for the *hypothesis that spatial variation in nutrient and metal distributions most strongly reflects land-use legacies*. This work will continue in CAP3, as will our environmental-justice research that examines the human consequences of these distributions.

Air quality: CAP2 research has shown that atmospheric deposition of N and organic C in desert parks within and surrounding the city are lower than modeled values, at ~5-7 kg N ha^{-1} y^{-1}. It is unclear, however, whether these results are caused by unusually low concentrations of N-containing aerosols or other atmospheric/climatic factors that may keep pollution aloft. Governmental air-quality monitoring is generally limited to a few compounds and performed in urban locations and transportation corridors in response to human-health concerns. Thus, our knowledge of the composition, distribution, and dynamics of the urban atmosphere across the CAP ecosystem is limited. *We hypothesize that air-pollutant concentrations attenuate rapidly beyond the urban fringe.*

Water quality: Enhanced material inputs to urban ecosystems may ultimately be transported via the wastewater stream or in stormwater to reach recipient groundwater, retention basins, or downstream river ecosystems. We will continue CAP research that examines transport and retention mechanisms in diverse water features (especially for N and C). In addition, we will initiate a longitudinal study of groundwater chemistry. Pharmaceutical and personal care products (PPCPs) and persistent organic pollutants (POPs) are ubiquitous in the global environment, derived from agricultural, industrial, and health-care products (Snyder et al. 2003; Westerhoff et al. 2005; Westerhoff et al. 2009). However, despite their origin in cities, the distribution, fate, and consequences of PPCPs and POPs for human health, wildlife, and biogeochemical cycles are unknown. We therefore will begin monitoring these compounds in CAP3, testing the hypothesis that *PPCPs and POPs will be abundant in recipient systems within and downstream from the metro area, with concentrations depending upon extent of connectivity to wastewater.*

Work Plan for Question 2: We will study fates of materials by continuing to: a) measure N deposition, air quality, and desert-ecosystem processes at control and fertilized plots situated across a rural–urban gradient; b) compare long-term trends in water chemistry on the major rivers entering (Salt and Verde rivers) and leaving (Gila River) the city; c) evaluate changes in water quality and organic compounds of Tempe Town Lake, an artificial lake established in 1999 in the Salt River bed that receives both purchased water and episodic stormwater; and d) measure soil nutrient and metal concentrations every five years as part of the Survey200 (Section II.A3). Connections between the “water” IPA and these activities are deep; for example, stormwater research bridges the two groups.

CAP3 will enhance the existing air-quality network in two ways. First, we will expand the spatial distribution of monitoring to regional open space parks distributed across the urban-rural gradient. We will measure additional compounds, including those crucial in biogeochemical processes (CO_2, HNO_3, NH_3) to supplement those routinely measured (NO_x, O_3, and particulate matter).

We will measure PPCPs and POPs in diverse samples, including stormwater runoff from urban landscapes, irrigation water used on landscapes, and lake and river samples. We will also revisit existing groundwater-quality databases to relate the spatial distribution of high-nitrate groundwater to current or past land use, and evaluate how it has changed as groundwater recharge has been enhanced.

Question 3: Are ecosystem services derived from biogeochemical processes distributed inequitably and how will this distribution change over the next 5–10 years?

Fluxes of nutrients and pollutants generate uneven concentrations in metro Phoenix. Significant changes in toxic releases and demographics have occurred over the past 15 years. From 1990–2006, total releases from Toxics Release Inventory (TRI) facilities declined from 2,300 to 700 metric tons while the population of Maricopa County grew by 80%. At the same time, Hispanic populations grew rapidly from 345,000 in 1990 to 1.7 million in 2006. *We hypothesize that the benefits of such declines are spread unevenly and that ethnic and racial minorities continue to be disproportionately exposed.*

Concentration of low-income minority residents and environmental pollutants into certain neighborhoods is primarily a function of economic and institutional drivers, the historic and continuing profile of emissions, and the behavior of households moving to adapt to market and environmental conditions. The capacity of ecosystems to dissipate or dilute pollutants may ameliorate the threat. Other contaminants, such as lead, reside in ecosystems for a long time.

In metro Phoenix, baseline lead concentration in soils (~20 ppm) derives partly from background geology, but anthropogenic sources (primarily coal combustion and lead paint) are responsible for higher levels, in some cases exceeding 200 ppm. An initial environmental-equity analysis shows that high lead concentration correlates strongly and positively with racial/ethnic minority populations and percentage of renters. These findings confirm our earlier studies demonstrating a strong and positive correlation between the concentration of TRI facilities and racial/ethnic minorities (Bolin et al. 2002). What remains unclear from these and other environmental-equity analyses is the degree to which biogeochemical services can alleviate threats to human health and well-being. Research that bridges ecology, ecosystem services, and environmental equity is just beginning (Pickett et al. 2007). Analyzing differences in the distribution of measured ecosystem services across a metro area within an environmental-equity framework is a fundamental goal (Boone 2008).

Work plan for Question 3: The flux of air pollutants and toxins in the CAP region threatens human health and well-being. We will continue to measure and model the distribution of toxic air releases using the TRI and the Hazards Density Index protocol developed by Bolin et al. (2002), and relate toxic distributions to changing residential patterns drawn from the Census (see Section III.A5). To examine the distribution of benefits from overall declines in toxic releases, we will conduct a longitudinal analysis of TRI releases and environmental-equity patterns, and use the EPA's Risk Screening Environmental Indicators database to model the fate of toxic releases in the atmosphere and human-health risks (www.epa.gov/oppt/rsei). In addition, we will continue to model air-pollution distributions (after Grineski et al. 2007), adding new air-quality monitoring data (Section III.B3), to track temporal change in environmental-equity patterns. Finally, we will conclude the environmental-equity analysis of lead soil concentration and identify historical and current sources of contamination.

B4. ***Human Decisions and Biodiversity***

The overarching questions of this IPA are: How do human activities, behaviors, and willingness to make tradeoffs 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 perceptions, values, and actions? Urbanization profoundly alters the composition, abundance, and distribution of nonhuman species (McKinney 2002; Schlesinger et al. 2008). Yet, biodiversity is key to some ecosystem services (especially cultural services). Reduced access to nature, the "extinction of experience" (Pyle 1978), is increasingly thought to be detrimental to human well-being (Shumaker and Taylor 1983; Ryan 2005). Previous CAP research has provided insights into the socioeconomic drivers of urban biodiversity patterns (Kinzig et al. 2005), functioning of urban food webs (Faeth et al. 2005; Shochat et al. 2006b), and effects of exposure to native desert landscapes on people (Yabiku et al 2008).

In CAP3, we will continue to document species occurrence, yet broaden our efforts to understand the underlying processes associated with species loss and change in urban settings. We will study direct and indirect human influences on biodiversity at scales ranging from organismal physiology to regional distributions, employing both descriptive and experimental approaches. We will continue to pursue understanding of the socioeconomic and policy drivers of habitat structure, and of the impact that access to biodiversity has on human well-being. CAP3 will build upon and refine understanding of the patterns of urban biodiversity in three ways. First, we will explore more detailed mechanisms that contribute to species loss and dominance in bird communities (e.g., competition, physiological stress) to explain why non-native species dominate in urban areas with extraordinarily high native richness. Second, we will explore the efficacy of efforts to conserve and restore “natural” habitats. And finally, to explore the feedback loop from human impacts on biodiversity back to impacts on human well-being, we will develop, compile, and quantify the first description of a complete urban food web that integrates humans and human activities with nonhuman biota.

Question 1: What mechanisms explain species loss or dominance and, ultimately, biodiversity in the urban environment?

Biotic responses to urbanization vary depending on the species (Deplazes et al. 2004; Huste and Boulinier 2007). CAP research has documented urbanization-associated changes in faunal community structure (Shochat et al. 2004) and proposed hypotheses to explain these changes. Two alternative views on the processes underlying patterns of animal species richness in urban areas have emerged: 1) the colonization-extinction balance and 2) species interactions. In the first view, species present in an urban patch are a combination of species colonizing novel habitats formed during urbanization and those remaining after local extinctions caused by isolation or habitat alteration (including stress; Marzluff and Rodewald 2008). In the second view, species interactions most strongly influence species richness by determining the degree to which competing species coexist. In this view, differences in ecosystem productivity or human resource inputs drive differences in diversity among urban habitats (e.g., Fig. 1.16). Previous research has suggested that biodiversity reflects both species-specific sensitivity and response to environmental factors and biotic interactions among competing species. (e.g., Shochat et al. 2006). CAP3 research is designed to identify conditions under which each of these mechanisms applies. *We hypothesize that interspecific competition plays a larger role in the highly productive mesic residential areas than in xeric or desert areas.*

Workplan for Question 1: Our biodiversity research program will entail: 1) continued observations, with additions of selected habitats; 2) experimental manipulations to reveal strength of biotic interactions; 3) detailed studies of physiological and behavioral responses to urbanization of native bird species; and 4) studies of a particular stressor —noise—on urban birds. In CAP3, we will continue to sample the abundance and diversity of birds, ground-dwelling arthropods, plant-associated insects (at Survey200 sites), and plants using our established methods. We will add plant-dwelling insects to our sampling of desert sites across the rural–urban gradient. We will again census birds in the 40 PASS neighborhoods during the survey year and one year after (2011-2012). This long-term dataset will allow us to detect changes in biotic community structure associated with changing social conditions (e.g., use of feeders, landscape management). We will expand our semiannual bird census by assessing the number of sites classified as “fringe” habitat and supplementing these, if needed, with up to five new sites. This addition will allow us to relate bird-diversity patterns to land-fragmentation patterns being documented in a cross-site study (see Section IV).

We will examine physiological and behavioral variables as factors that may control the adaptability and success of birds in urban environments. We will use sedentary avian species native to the Sonoran Desert to assess both intra- and interspecific differences in physiology and behavior. Before, during, and after breeding seasons, we will collect size and condition measures as well as blood samples from each species at selected Survey 200 sites. We will measure blood samples for reproductive and stress hormones, natural antibodies, metabolic products, hemoparasites, and leucocytes, which is a reliable indicator of chronic stress (Deviche et al. 2005, *in press*). Finally, we will conduct behavioral tests on males to quantify territoriality. As ambient conditions in the Sonoran Desert reveal interannual variability, we will distribute sample collection over several years. We will analyze inter- and intraspecific differences in physiology and behavior as a function of habitat.

To test our hypothesis, we will census key taxa across urban habitat types, make physiological measurements, and conduct manipulative experiments. We will expand experiments on foraging behavior in birds, manipulating interspecific competition through exclusion of dominant and highly efficient foragers in mesic, xeric, and desert habitats using cages or feeder designs (Fig. 2.12). Within residential habitat types, we will address sociodemographic drivers of variation in resource inputs.

To predict the effects of noise on urban birds, we will evaluate relationships between species-specific frequencies of calls or songs and bird abundance in high-traffic areas (Rheindt 2003) and measure changes in the acoustic frequency and amplitude of calls and songs with increasing noise of habitat generalists and specialists. Preliminary evidence shows that noise is, like other disamenities, inequitably distributed across the metro area, with lower-income areas bearing a higher burden (Warren et al. 2006). Using our acoustic data, we will analyze the implications of the spatial distribution of noise for people, incorporating this analysis into our land architecture–tradeoffs model.

Figure 2.12. Caged tray (left) and feeder design (right) used for experimental manipulations of interspecific competition. In feeders, placement of short perches foils attempts by non-native house sparrows to dominate feeders, allowing native goldfinches (pictured) to feed.

Question 2: Can conservation and restoration of 'natural' habitats within the urban environment restore "natural" animal communities?

A key question for planners and managers is whether constructed landscapes meant to imitate the desert are functionally equivalent to them. In general, desert-like urban landscapes do not resemble the native desert's trophic dynamics, richness, and species composition (Faeth et al. 2005), although native biotic pollinators can be sustained through native plantings (McIntyre 2000). Previous CAP research has focused on residential landscapes and upland desert remnants. CAP3 will expand this analysis to riparian zones, testing the *hypothesis that the riparianized desert (Section III.B3) and restored riparian habitats in the urban setting support key functions and biotic communities found in native riparian areas.* Riparian ecosystems often have high biodiversity, providing critical habitat for many faunal species (Powell and Steidl 2002). These structurally complex ecosystems positively influence species richness and abundance, especially of avifauna (Sanders and Edge 1998). However, the importance of riparian habitat is less understood in amphibian and reptile communities (Naiman et al. 2005). Herpetofauna respond to structural changes to their habitat (Pianka 1967) and are important consumers and predators within ecosystems (Burton and Likens 1975). Their presence and abundance can be effective indicators of habitat change and restoration success.

<u>Work Plan for Question 2</u>: We will evaluate the efficacy of riparian-restoration efforts along the Salt and Gila rivers for avifauna and herpetofauna. Specifically, we will quantify the abundance, diversity, community structure, physiological condition of reptiles, amphibians, and birds of at least five restored urban riparian areas and contrast these with five adjacent, unrestored areas. We will relate the abundance of animal taxa to characteristics of these ecosystems to determine those features of riparian habitat that best support abundance and diversity. Quantifying blood parasites and types

of leucocytes will allow us to describe the degree of physiological stress and chronic stress experienced in these ecosystems and to compare stress levels in unrestored habitats.

Question 3: Through what pathways do humans modify urban food webs, and how do these changes cascade through food webs to influence the delivery of ecosystem services?

Human-influenced changes in biodiversity have consequences for ecosystem function (and thus services) and for human perceptions and values. For example, urban residents may view replacement of native species by non-natives positively (e.g., game fish) or negatively (e.g., roof rats). We will use a food-web approach to better understand how (rather than just how much) human activities, behaviors, and values modify diversity, and begin to link specific attributes of biodiversity and outcomes and behaviors. Food webs provide an alternative view of community structure that is not inherent in simple indices of biodiversity. Food webs add a trophic or consumer-resource perspective that will allow us to functionally understand how biodiversity is modified and valued in the urban setting. Our goal will be to produce the first detailed diagram of "The Urban Food Web" analogous to descriptions of oceanic food webs found in biology textbooks. Like the marine counterparts, our food web will include humans and the effects of human activities (e.g., pest control, garbage subsidies, agriculture) on food-web architecture. As humans have fished down the food web in marine ecosystems (Pauly et al. 1998), we suspect that *humans will play a similarly central role in modifying the height and complexity of urban food webs.*

<u>Work Plan for Question 3</u>: We will organize biodiversity data into a structure that more naturally includes humans (as consumers, resource providers, and part of the food web) and the services/ disservices that components of biodiversity provide. We will combine food-web graphs (Cohen et al. 2003; Fig. 2.13) and the patch-dynamic approaches from landscape ecology (Wu and David 2002) to assemble an urban connectance food web (i.e., showing trophic and non-trophic interactions) across the diverse CAP landscape. We will initiate monitoring programs to quantify the richness and abundance of reptiles, amphibians, and small mammals. To address strikingly contrasting patterns of abundance and biodiversity between plant-dwelling and ground-dwelling arthropods, we will sample plant-dwelling insects at Survey200 sites characterized by similar land use and cover as those locations where ground-dwelling arthropods are collected. New diet analyses of consumers (birds, mammals, lizards, arthropods) coupled with natural-history accounts in the literature allow us to quantify trophic relationships and construct binary food webs at various spatial grains and scales. Finally, we will expand PASS research (Section III.A4) to map human activities that have cascading effects in food webs (e.g., cat ownership, bird feeders, water and fertilizer use) and to assess how humans alter food webs through changes in services such as pest control, pollination, or biodiversity.

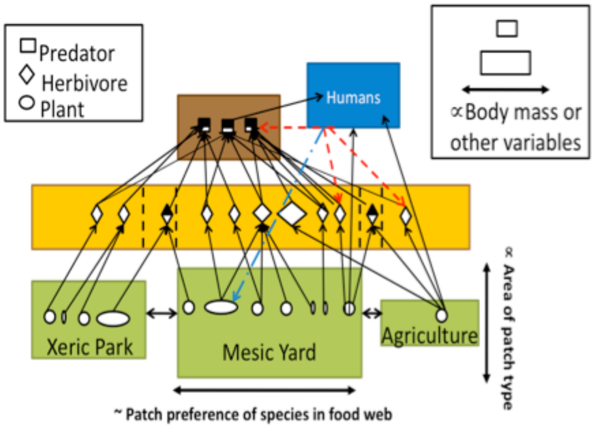


Figure 2.13. Conceptual illustration of an urban food web using a synthesis of patch dynamic theory (Wu and David 2002) and body-size based descriptions of connectance food webs (Cohen et al. 2003). Vertical arrows are trophic relationships pointing to the consumer. Horizontal arrows connect patches via plant dispersal. Dashed lines indicate passable patch boundaries for mobile consumers (predators cover all patches here). Open and half-filled symbols indicate patch specialists and generalists, respectively.

C. Research Synthesis and Future Scenarios of Change

In CAP 3, we will embark upon a two-part synthesis program (Fig. 2.5). The first step will be to summarize and synthesize past research; the second step will address future SES scenarios for central Arizona. These scenarios, based upon on a new land architecture–tradeoff model, climate-change scenarios, stakeholder workshops, and narratives and products from related projects, will be developed in parallel with a LTER network scenario initiative (Foster et al. 2009). Taken together, these activities will present an integrated view of what "is," "may be," and "could be" in regard to sustainability of the SES.

C1. ***Synthesis of 12 Years of CAP LTER Research***

In CAP3, we will undertake a major synthesis of our research results to date, focusing on the research question guiding CAP1 and CAP2: "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?" After 12 years of CAP research, it seems appropriate to approach this question in a way that would not merely lead to additional and refined research questions. The answer to this guiding question will represent the best of our collective knowledge and will therefore entail active participation of all CAP researchers—past and present. Answering this question will allow us to critically examine: 1) the overall state of our knowledge; 2) the accomplishments and societal as well as scientific utility of this knowledge; and 3) any needed adjustments to future CAP research. Because CAP3 has shifted its focus to form a natural "step function" in our work, we are well poised to embark upon this synthesis.

Recognizing that the research results, expertise, and enthusiasm of all CAP researchers are needed for a successful synthesis, we will conduct a series of workshops at the Decision Theater. Before these workshops, we will collect and arrange the results of foundational, crosscutting projects, and those of the previous IPAs into matrices and other visualization tools, to support interactive synthesis activities among participating CAP researchers (cf. Wiek and Walter 2009). The workshops will comprise half of our monthly meetings during Year 2, culminating in a major workshop/retreat. These workshops will result in a CAP synthesis volume to be edited by Charles Redman, and in visualization and data products to be used in the scenarios workshops (below).

C2. ***Sustainable Futures for Central Arizona***

Building upon the 12-Year Synthesis, we will develop future scenarios for the central Arizona SES that address the critical question, ***How do biophysical drivers (e.g., climate change) and societal drivers (e.g., the pattern of land-use change, or land architecture) influence the interaction and feedbacks between ecosystems and society as mediated through ecosystem services, and thereby influence the future of the urban SES?*** This effort will be integrated with other projects at ASU and in Phoenix, with local and regional stakeholders, and with LTER network-wide scenario activities. We aim to move beyond the question of what *is* our relationship with nature and its implications for sustainability, to those of what will be and what *ought to be* our relationship relative to what is sustainable. The time to raise this question is opportune; Phoenix and Arizona are increasingly posing questions about what their citizens hope for their future (Center for the Future of Arizona 2009). Moreover, Phoenix is a city at risk of the potential negative impacts of global climate change. Increasing demand for water and land due to the rapidly growing population (Fig. 2.14) are on a collision course with high-confidence predictions for a drier, hotter future with reduced water availability in the Southwest (Seager et al. 2007; Barnett and Pierce 2009; Karl et al. 2009; Buizer et al. 2010). The human impacts of higher temperatures, energy price increases, and water scarcity are already evident in low-income populations during the current recession.

We have discussed future thinking and scenario activities as CAP research objectives from the outset. Here we propose scenario activities that link our growing, real-time information base on the

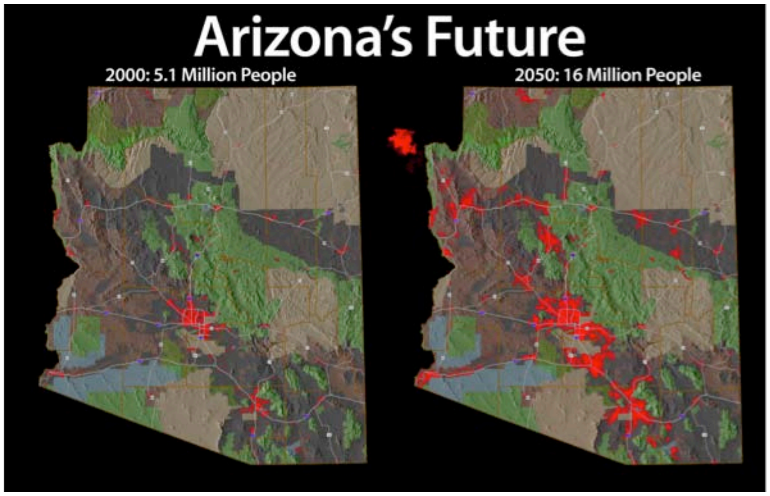


Figure 2.14. Current (A) and projected (to 2050, B) urban extent in Arizona, USA. Maps by the Maricopa Association of Governments.

SES with anticipatory capacity building (Guston and Sarewitz 2002), responding to the repeated call for future-oriented research in sustainability science (Swart et al. 2004; Komiyama and Takeuchi 2006) that generates results relevant to governance, policy, and decision making. Scenario methods have been proposed and applied in many land-change research projects (Robinson 2003; Xiang and Clarke 2003; Nassauer and Corry 2004; Wiek et al. 2006; Patel et al. 2007; Walz et al. 2007). Here, we will take two approaches to scenarios. The first approach assesses *sustainable land architecture* using a spatially explicit model to evaluate the effects of anticipated land and climate changes on the delivery of ecosystem services, as well as physical tradeoffs among multiple services. The second approach will develop *integrated participatory scenarios* in workshops where stake-holders (including scientists and various decision makers) envision potential futures for Arizona.

We will use our *Sustainable Land Architecture* scenarios to assess vulnerability, resilience, and sustainability under current and potential climate drivers. Our rationale is based on the premise that the critical attributes of sustainable SESs cannot be addressed adequately without: 1) quantitative assessments of ecosystem services–human outcome tradeoffs; and 2) consideration of the effect of land architecture (kind, amount, distribution and pattern) on these tradeoffs (Turner et al. 2007; Turner 2009). We will apply this synthesis activity to the metro area and to selected neighborhoods that differ in race/ethnicity and social-class composition, set in the context of a regional megapolitan that may reach 10 million by 2040 (Pattison and Vest 2009).

We will examine 12 measures of 8 inputs relevant for 4 ecosystem services, measures of 3 human outcomes, and apply both to individual land-cover categories and their architecture for 2010 as a base case (Fig. 2.15). We will generate parcel- to metro-level assessments of the physical tradeoffs (economic tradeoffs are treated in another ASU effort) among ecosystem services and between them and the human outcomes. We will generate these assessments through an integrative, tripartite modeling exercise involving exploratory spatial data analysis, spatial econometric analysis, and input-output assessments of the requirements for market goods and services. We will draw upon data from throughout the units and projects of GIOS, including our systematic land-classification activities (Section III.A1), and analyze these at ASU's GeoDa Center on spatial analysis. The resulting output will allow us to test a large array of ecosystem service and sustainability themes and, when linked to a regional assessment effort, permit tests of the spatial dynamics (neighborhood-to-region and vice versa) of services and outcomes. We will collaborate with the Decision Theater to generate decision-friendly version of the models, co-produced with Phoenix and Arizona decision makers and community organizations and activists, which permit tradeoffs assessments under different visions of the future of the Phoenix metro area.

To incorporate climate change into these scenarios, we will continue to refine our understanding of how past land-use changes contribute to spatial variability of urban climate. We will then expand this inquiry to examine how future global climate change will influence climate in the region, with consequences for ecosystem services and human-outcome tradeoffs and on people and neighborhoods (see Section III.B1). We will use results from research conducted under the leveraged

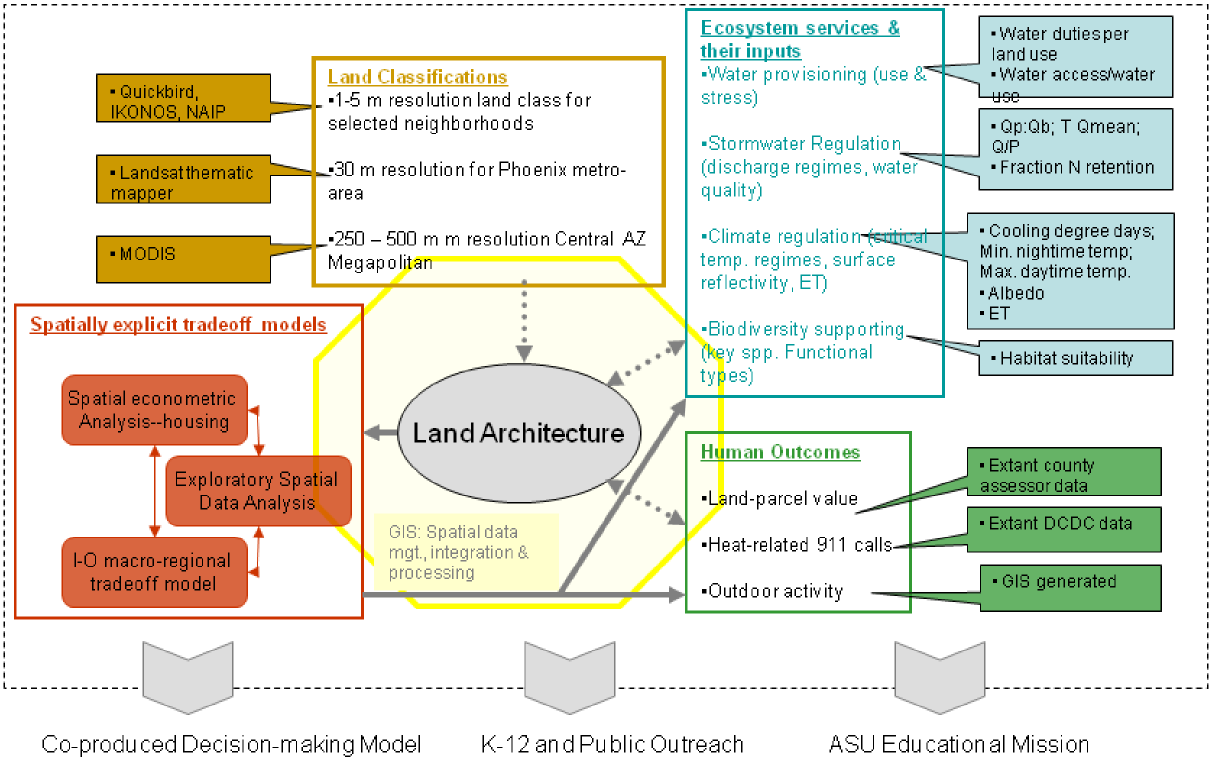


Figure 2.15. Scheme showing the components and integration of the Sustainable Land Architecture project. Ecosystem services (blue) and human outcomes (green) and their tradeoffs will be assessed for different scales and configurations of land use and cover, using spatially explicit tradeoff models.

NSF grant (GEO 0816168), as well as research conducted under a regional partnership, to downscale a range of global climate-change scenarios to central Arizona and estimate the impacts of such changes on streamflow, water supply, and urban water management (Quay *in review*).

Our *integrated participatory scenarios* (after Bolte et al. 2006; Y. Liu et al. 2007; Wiek et al. 2008; Wiek et al. 2009; Hulse et al. *in press*) will build upon the *sustainable land architecture* scenarios, our 12-year synthesis, and new data and models from IPA research (Section III.B). We will consider several SES futures in "context" scenarios that include biophysical (climate) drivers potentially combined with internal changes in the SES that result from economic, political, and socioeconomic drivers. These futures will consider, for example, a metro area that shrinks and grows in population size and area, or that seeks or discourages smart growth. We will work with DCDC and other ASU urban researchers to construct these futures with metro area leaders and planners as full partners, using ASU's interactive Decision Theater as the venue. Scenario activities will follow an integrated participatory-scenario approach and will be connected with proposed DCDC and ongoing UVCC work, as well as LTER-related scenario work (Peterson et al. 2003; Foster et al. 2009).

V. Regionalization, 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 SES. Although past comparative work on environmental justice (Boone et al. *in prep*.) and climate (Brazel and Heisler 2009; Brazel et al. 2000) has focused on the two urban LTER sites, other LTER sites recognize the importance of understanding urbanization adjacent to and beyond their site boundaries. This recognition presents us with new opportunities for collaboration. Regionally, we will continue research that focuses on urbanization and land fragmentation at three Southwestern sites (CAP, JRN, and SEV) and two grassland sites (SGS and KNZ). This initiative will move into a second phase, examining the social and institutional drivers of land fragmentation and linking fragmentation to other biophysical data on biodiversity and water.

Other cross-site research with BES, PIE, and FCE spans ecosystem types and geographies to explore: relationships among the cognitive, institutional, and structural 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*), will employ OBIA using a common, parcel-scale, classification scheme coupled with detailed measurements of ecosystem processes and human attitudes and actions.

Both the land fragmentation and residential landscape efforts feed into the larger 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. At the network level, CAP scientists will continue to be active in the LTER social-science community through initiatives that seek greater integration of social-science research into ecological investigations. Our new emphasis on scenario building allows us to share our lessons learned with other LTER sites and to contribute to scenario exercises at the regional, national, and international levels. We are committed to engaging in cross-site activities and will host a regional LTER symposium in 2011.

VI. Response to the CAP2 Mid-Term Review Recommendations

The highly complimentary CAP2 midterm review made a series of suggestions, most of which we have adopted. For instance, we now include two hydrologists as senior scientists on the project, we have brought on agency scientists as senior personnel, and our new scenario activity will engage others outside academia. We continue to work on project integration and ensuring that collaborators are truly working together—an ever-present challenge in an interdisciplinary study. We are implementing strategies to enhance communication across these groups, which are composed of ~45% social scientists and ~55% biophysical scientists and engineers. We retain our openness to new investigators and have added 36 new scientists in several disciplines to our team of Co-PIs and senior personnel.

VII. Expected Outcomes and Significance

Since its inception in 1997, CAP LTER has been a leader in developing theory and knowledge of urban socioecological systems. The tremendous challenge of truly integrating social and ecological perspectives is ever present, yet we have made great progress and anticipate continued evolution of the conceptual framework, information base, and societal application of the knowledge we are producing. Our work's significance cannot be understated: the simple facts that most of the world's population lives in cities and that urbanization tops the list of rapid environmental changes means that we must look to SESs for solutions to the global sustainability challenge. Inherent in LTER studies is close attention to a single place and, in some respects, this attention belies sorely needed comparative research at continental-to-global scales (Grimm et al. 2008b; Peters et al. 2008). We will continue our work to extend the relevance of our findings through cross-site, network, and other collaborations.

The interactions of people and ecosystems are at the first level of place-based analysis. They have consequences that extend beyond the immediate locations of human population agglomerations. Nonetheless to understand the interconnections we must start with the co-location of people and ecosystems and consider what is unique about the climatic and biome conditions that support both. Our land-change research recognizes these fundamental interconnections even as it acknowledges they are not fully understood. Nonetheless, we exploit the ongoing experiment associated with anticipated land and climate changes, and strive to understand their effects on ecosystem structure and function and hence the delivery of ecosystem services. Our strategy of evaluating tradeoffs among multiple services and human outcomes at neighborhood, metro, and regional scales in a spatially explicit way, offers the potential for an unprecedented, comprehensive analysis that contributes to emerging theory on ecosystem services (Carpenter et al. 2009; Nelson et al. 2009; Turner 2009; Bennett et al. 2009). Equally important, it offers the prospect for using that understanding to inform the public and policy makers in the hope that some uses are redirected away from the most harmful and undesirable outcomes and toward the ones more likely to provide sustainable levels of human activity and associated ecosystem services.

Communication and engagement are essential to our integrated view of research, public engagement and policy formation. The Decision Theater provides a visualization environment to achieve this objective, wherein the sustainable land architecture and integrated participatory scenario work will be used in the co-production of knowledge with local, regional, and state decision makers, NGOs, and the public.

Part 3 – Project Management

The core objective of project management within CAP LTER remains constant: to enable CAP scientists to generate significant research results that are disseminated through appropriate media and archived in a continually expanding database. To achieve this objective, CAP has established a management structure to manage and distribute project resources, engender research integration across a diversity of disciplines, and conduct core research, education, and information-management activities (Fig. 3.1). Although the principal metric of success for any scientific endeavor is the quality and quantity of the research it produces, a sound management structure ensures accountability and efficiency of resource use and lays the foundation for innovative science.

Lead PI and project director **Nancy Grimm**, an ecosystem ecologist and biogeochemist, will provide leadership direction for CAP3 in conjunction with an *Executive Committee* and additional advisement by a *Research Leadership Team*. Grimm has been the lead PI and co-director of CAP for 12 years and co-leads CAP research on biogeochemical fluxes. **Charles Redman**, an archeologist focusing on sustainable urban systems, has also been co-director for 12 years but will step down from this role in CAP3 to take a seat on the Executive Committee. Grimm and Redman will co-lead the synthesis and scenario activities, with Redman taking primary responsibility for coordinating the synthesis volume.

The project director is responsible for the overall quality and direction of the research of CAP. She is the point of contact with the NSF program officers, serves as a member of the LTER Science Council, and works with the university administration to ensure the long-term integrity and security of CAP infrastructure resources. Grimm has recently accepted an appointment on the LTER National Advisory Board and looks forward to learning from that experience to improve CAP's management. Grimm and Redman developed an approach to leadership in CAP1 and CAP2 that will be carried forward in CAP3. Its hallmarks are: openness to participation from new scientists, particularly those at the beginning of their careers; some flexibility in allocation of financial resources to provide "seed" support for exciting new ideas; maintaining a strong, central core of project-wide technical and management personnel; and enabling participating of multiple disciplines.

The *Executive Committee* is a new entity within CAP's management framework and will consist of six persons: **Billie Turner**, a land-change geographer; **Daniel Childers**, a wetland-ecosystem ecologist; **Christopher Boone**, an urban geographer; **Sharon Harlan**, an environmental sociologist; Redman; and Grimm (Table 3.1). All are active in CAP research and have demonstrated leadership capabilities: Turner has led a large, interdisciplinary project focused on the Yucatan; Childers is the former PI of the FCE LTER; Boone is PI of the proposed Southwest ULTRA project; and Harlan has directed the PASS and UVCC projects. The Executive Committee will meet at least nine times per year and will make decisions concerning research directions and changes in budget or personnel. This committee also will comprise a search committee for any postdoctoral scholars, together with the likely primary advisor of the post-doc.

The *Project Management Team* has the responsibility for the day-to-day operation of core research, educational, information management, and general project-management activities.
The team meets monthly during the academic year with the project director to discuss management issues and to troubleshoot potential problems. Site manager **Stevan Earl** manages field and laboratory operations for our long-term monitoring and experiments, including, among others, Survey200, the long-term fertilization experiment, and NDV. He supervises a cadre of field and analytical technicians, maintains access and research agreements, ensures proper management of core-monitoring data, maintains CAP LTER infrastructure, and supports graduate student, postdoctoral, and faculty research programs. Education manager **Monica Elser** directs the Ecology Explorers team to design and deliver education and outreach activities to K-12 teachers, students, and the general public in the greater Phoenix area. **Philip Tarrant** is the new information manager and is responsible for providing training on data management for researchers, working with researchers to design and

populate databases, supervising data technicians, and ensuring that datasets are available on the website. **Marcia Nation** will continue to serve as the project manager; she manages project-wide communication and planning, facilitates interactions with DCDC and other ASU projects, and coordinates project reporting to the NSF.

The *Research Leadership Team* includes members of the Executive Committee and Project Management Team as well as other CAP Co-PIs/Team Leaders: **Kerry Smith**, an environmental economist; **Jianguo Wu**, a landscape ecologist; **John Sabo**, a community ecologist; **Chris Martin**, an urban horticulturist; Assistant Director of Water Services for the City of Phoenix **Ray Quay**; and **Susanne Grossman-Clarke,** an atmospheric scientist. This team will meet twice per year to make recommendations to the Executive Committee for support of research projects proposed by the IPAs and other research teams. CAP's budget includes allocations for the foundational research activities. Other funding—faculty summer salary, graduate-research assistantships, and graduate-research grants—are allocated on an annual basis, with the Research Leadership Team making decisions on allocations among groups and individual leaders making decisions on allocations within their groups.

The project director and the Research Leadership Team work to engage a diversity of scientists (including our 18 co-PIs; Table 3.1) and community partners in CAP research and outreach activities. The project manager uses a simple, yet effective, e-mail distribution list to inform scientists and community partners about events and opportunities. In addition, we use the CAP website and the Sustainability Digest (a weekly bulletin originating from GIOS that reaches a wide audience in metro Phoenix) to disseminate event notices and project news. All Scientists Meetings, held monthly during the academic year, are an opportunity for students and faculty scientists to meet and share research results. Based on a recommendation from the CAP2 site visit committee, these meetings have focused on topics that promote research integration among the social, biological, engineering, and physical sciences and have been a focal point for introducing new scientists to CAP. During year 2 of CAP3 (and possibly beyond), these meetings will be devoted to synthesis activities. CAP's annual poster symposium, which attracts campus-wide participants and attendees, is another vehicle for promoting integrated science. Held each January, this symposium features a keynote address, poster sessions, plenary speakers, and meetings of the thematic research groups. Every other year, CAP convenes a midsummer workshop or retreat to consider special topics or project planning, and every third year we plant to convene a regional symposium with SEV, JRN, SGS, and NWT.

CAP has created a platform for urban-ecological research in the Phoenix region, providing base funding, infrastructure (including sites and data), and other support for scientific endeavors. We allocate nominal amounts to individual investigators, often to jumpstart new research, with the understanding that this funding should be used to garner additional resources. CAP scientists have been successful in this respect, leveraging $38.6 million in grant support since 1997 (Fig. 1.18). We also initiated a graduate funding program in CAP2 that will grow substantially in CAP3, in collaboration with a new, graduate student-initiated program, "Graduates in Integrated Society and Environment Research" (GISER; see details in Part 5).

The GIOS at Arizona State University will continue to serve as CAP's administrative home, providing in-kind support for grant administration and fiscal management, human-resource management, web and print communications, meeting and event planning, and technical support. CAP managers have offices in GIOS, and the project benefits from the surrounding transdisciplinary environment, including frequent interaction with faculty members in the School of Sustainability, some of whom have become involved in CAP. Our laboratory activities are housed in the Goldwater Environmental Laboratory, a shared-use facility available to ASU research staff, faculty members, and students. Cathy Kochert will continue to serve as the CAP laboratory manager, ensuring the quality of chemical analyses, training staff, and developing methods.

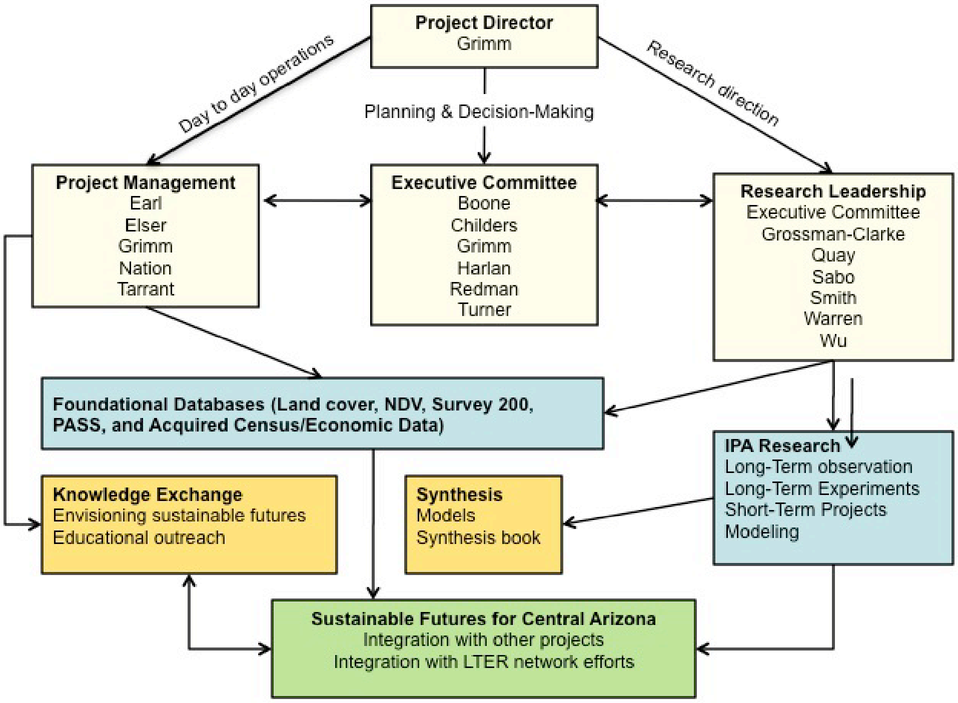


Figure 3.1. Organizational structure for CAP3, including relationships among research components.

Table 3.1. Co PIs and leadership roster for CAP3.

Co-Principal Investigators/Executive Committee/Research Leadership Team		
Nancy Grimm	Life Sciences	Ecology
Christopher Boone	Human Evolution & Social Change; Sustainability	Geography
Dan Childers	Sustainability	Ecology
Sharon Harlan	Human Evolution & Social Change	Sociology
Charles Redman	Sustainability; Human Evolution & Social Change	Anthropology
Billie Turner	Geographical Sciences & Urban Planning	Geography
Co-Principal Investigators/Research Leadership Team		
Susanne Grossman-Clarke	Global Institute of Sustainability	Climatology
Ray Quay	City of Phoenix	Planning
John Sabo	Life Sciences	Ecology
Kerry Smith	Economics	Economics
Paige Warren	Natural Resources Conservation, U. Massachusetts	Ecology
Jianguo Wu	Life Sciences, Sustainability	Ecology
Other Co-Principal Investigators		
David Casagrande	Sociology & Anthropology, W. Illinois U.	Anthropology
Sharon Hall	Life Sciences	Ecology
Kelli Larson	Geographical Sciences & Urban Planning; Sustainability	Geography
Chris Martin	Applied Sciences & Math	Horticulture
Paul Westerhoff	Civil, Environmental, & Sustainable Engineering	Engineering
Abigail York	Human Evolution & Social Change	Political Science

Part 4 – Information Management

CAP Information Management (IM) has the main goal of providing technologies that support data collection, enable dataset discovery and access, and promote data integration and analysis across disciplines. We maintain high standards for data archiving and documentation to provide quality data and metadata. The IM team stays well informed about the applicability of the newest technologies, strives to provide access to those technologies for researchers, and continues to participate in standards development and implementation.

The IM team includes the information manager, a specialist in Geographic Information Systems, and a student programmer. A centralized system administration provided by GIOS supports the core team. However, over the years we have leveraged the IM activities through many externally funded projects (NSF ABI, BRC, ITR; the Arizona Water Institute, the Arizona Community Foundation) and the IM team has gained programmers and web developers who have contributed to the existing codebase. The IM team has an excellent track record of engaging in LTER network activities. We implement network approaches to allow for the highest degree of network-wide interoperability. CAP participates in all network-wide databases and complies with IM review criteria. We have recently established an Information Management Advisory Committee to guide our future efforts in and foster interactions with our researchers.

Infrastructure

GIOS provides a computing solution based on four virtual servers, with storage space on Netapp filers (network attached storage) to all its associated projects, including CAP, via ASU's UNIX Virtual Server facility. The database, development, and production web servers are hosted on this server farm, which is designed to bring the advantages and economies of scale of professional IT facilities to university research projects. As well as providing significant server resilience, consolidation into a single farm allows IT staff to maintain proper backups of the stored data, meeting short-term data-protection needs. The staff also performs regular security sweeps, searching for vulnerabilities or unusual behavior. Local connectivity runs at 100Mbs; high-bandwidth connectivity is through ASU’s connections to the Abilene backbone. Over 4Tb of storage space is available for research and data archives. We address long-term data protection through regular technology transfers to maintain current standards for hardware and software. This strategy minimizes the risk of data loss through media or format obsolescence.

Data Archives

We archive a wide range of datasets, including foundational datasets, long-term monitoring datasets from the IPAs, student-project data and supporting third-party data. Both tabular and spatial data are stored in relational database systems (MySQL and PostGIS). Metadata are entered into the these systems, from which XML files in the Ecological Metadata Language (EML 2.1.0) are generated. EML files are stored and managed in a native XML database system (eXist). The eXist architecture provides functionality to search, deliver, and format metadata via REST style web services. A recent workshop funded by the LTER Network Office (LNO) to design and implement a research-project database has been leveraged to deliver dataset metadata and protocols to the CAP website using XQuery documents in eXist.

A document archive holds most journal articles, posters, reports, and white papers in electronic format (pdf). Our image archive includes photos taken as part of research projects and images of graphs and maps. Both the document and image archive are on a central server that our researchers can directly access. The sample archive contains soil and water samples; plant-voucher specimens are held in the ASU Vascular Plant Herbarium. All archived materials are documented in the database and searchable on the website. Electronic resources except for copyright-protected journal articles are downloadable.

Supporting Data Collection

CAP information management supports several aspects of data collection: automated data streams from sensors, field-data entry, data mining, and data preparation. An automated system captures sensor data streams and transfers them into permanent storage undergoing quality-control routines. Long-term field data are supported by online input screens that provide maximum quality control during data entry. Chemical processing of field samples was streamlined during CAP2, with all samples bar coded with a sample ID. The sample ID is then scanned into the analytical machine and associated with each chemical analysis. Machine-generated concentration data are then uploaded into the central database. Short-term research projects generally provide data after their collection. The IM team cleans and normalizes the data, which they then import into the central database. The nature of the process provides a similar quality-control mechanism as the data-input screens.

Enabling Data Discovery and Access

CAP has adopted and posted the LTER General Data Use Agreement and implements a two-tiered data-access policy, with most data publicly available. Only copyright-protected, third-party data and selected human-subject data are not public. Most human subject data, however, have been stripped of identifying information and are publicly available through our data catalog. Data are presented via a web-based portal that accesses data from the underlying databases. Most data are presented to the user as comma-separated value files, selected because of this format's portable nature. Other documentation including metadata, publications, posters, and protocols are available through the web interface (see Fig 4.1). We make all long-term monitoring data available to our researchers as soon as they are entered and to the public within a year of collection. Investigator- and student-supplied data usually become available after publication. Nonpublic data are available to the CAP researchers via read access to our archive share on a central server and database access or through custom queries run by the IM team. The online data catalog logs downloads with minimal information as to who is downloading which datasets and why. We average ca. 600 downloads a year (Fig. 4.2).

Promoting Data Integration and Analysis Across Disciplines

Cross-discipline data integration is one of the major challenges faced by LTERs and the wider eco-informatics community. At CAP, we have taken experimental steps towards this goal by storing some of the more standardized datasets in the "Observation Data Model." This model, intended for time-series datasets, developed by the Consortium of Universities for the Advancement of Hydrologic Sciences (CUAHSI: http://www.cuahsi.org), standardizes attributes and data access, both of which aid in data integration. We are exploring other data models and semantic integration via ontologies, all in the context of the NSF-funded INTEROP grant "Scientific Observations Network."

Recent Changes in the Information Management Team

As of fall 2010, our CAP2 information manager, Corinna Gries, resigned to take a position as the NTL information manager. Gries has continued to work with our management team to enable a smooth transition to new leadership. In January, 2010, Philip Tarrant began working as CAP's information manager. Tarrant brings extensive experience in informatics, project, and personnel management from the business sector, coupled with a research interest (and MS degree) in urban conservation ecology and a special skill in creative writing. With a graduate certificate in geographic information science and recent research experience using remotely sensed data, Tarrant is well placed to explore the potential for spatial and tabular data integration. In particular, he is interested in extending the data synthesis efforts at CAP, with a strong desire to extract the maximum value from CAP’s substantial data pool. Tarrant’s immediate plans are to spend some time at the LNO to become more familiar with the LTER information management system overall.

In addition to this change, our plans for enhanced and comprehensive remote-sensing image analysis call for a shift in the arrangements for image acquisition, analysis, and data documentation and storage. We expect to hire a MS-level GIS technician, who will work primarily in the School of Geographic Science and Urban Planning’s new Remote-Sensing Laboratory for Sustainability (Soe Myint, Janet Franklin, and B.L. Turner, co-directors), but who will be the primary interface between this laboratory and the CAP database. Given our objective to compile and utilize these and other data in a visual environment for scenario development, we also plan to develop interfaces with the Decision Theater’s data repository and visualization capabilities. Finally, through our long-standing relationship with the geologic remote-sensing laboratories at ASU, we are collaborating (with funding provided by a recent LTER supplement) in the pilot development of new software called J-Earth that will enable clipping and access of any desired portion of remotely sensed images. We have formed a working group on remote sensing, GIS, and image analysis for central Arizona with the objective of integrating these diverse efforts and providing a standard platform for access to imagery (and classified products) by researchers interested in this area.

Future Plans

Data-enabling integration is an area that the LTER network and associated information managers will focus on in the near future. Much energy will go into establishing standards and collaborations to make LTER data more useful to meta analyses. We will participate fully in this effort, starting with integrating our metadata with the “Data Access Server” developed by the LNO and submitting our data to PASTA (Provenance Aware SynThesis Architecture). CAP has always been a willing early adopter and tester of new ideas and will continue to serve on the forefront of network-wide IM developments.

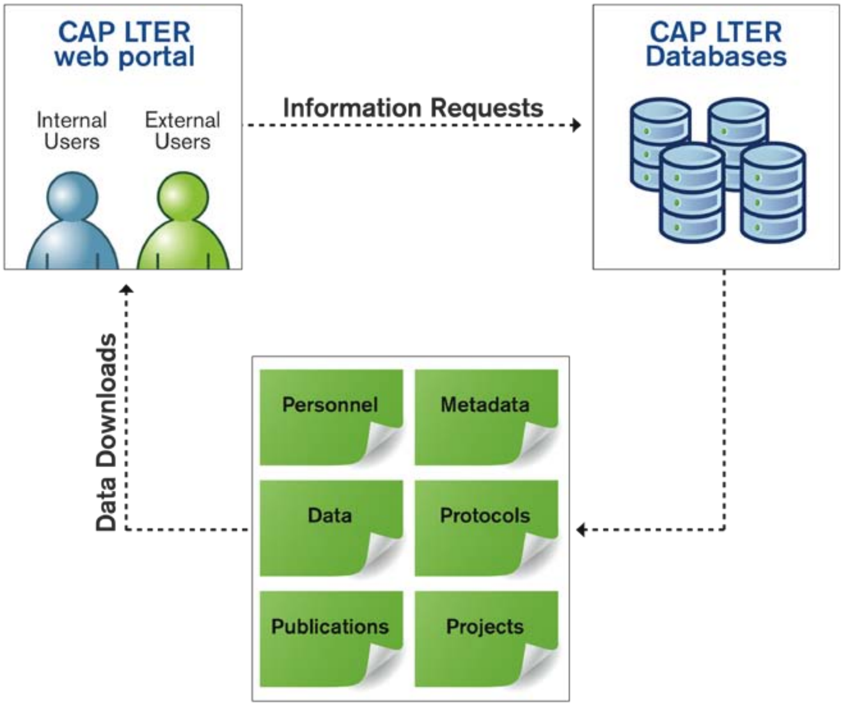


Figure 4.1. Schematic of data management system for CAP3.

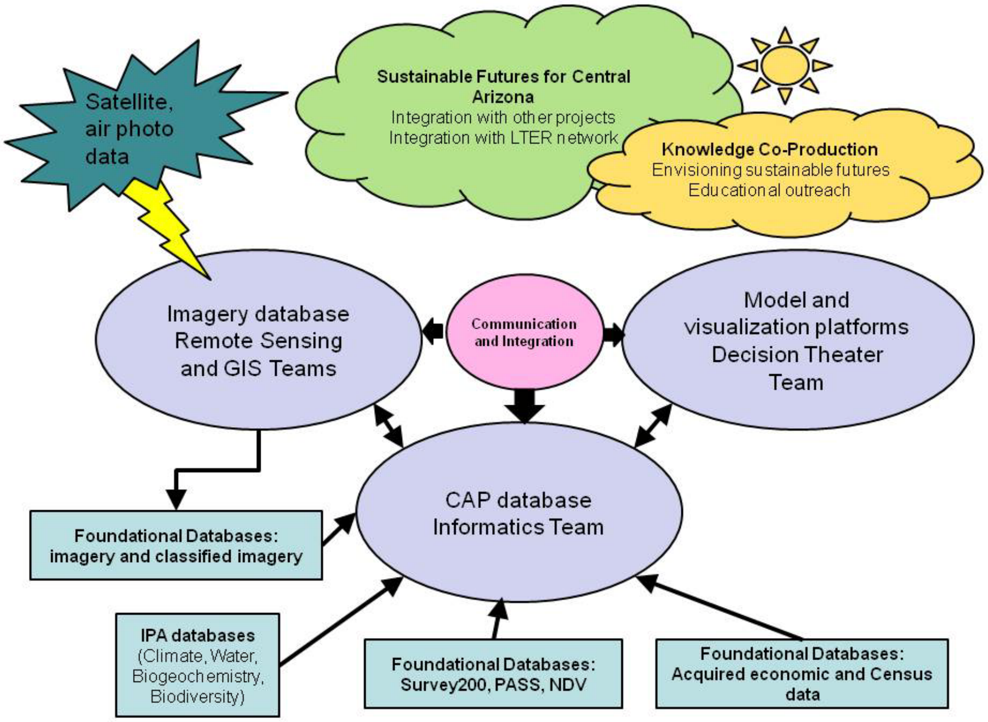


Figure 4.2. Work flows and interactions among remote sensing, GIS, visualization/modeling, and Informatics labs and teams in acquisition, processing, and storage of project data, imagery, and acquired data. All elements work together and with related projects and stakeholders, toward co-production of knowledge about sustainable futures for central Arizona.

Part 5 - Education and Outreach

Ecology Explorers 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 (Fig. 5.1). 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). We will conduct similar formal evaluations of Ecology Explorers in CAP3. We will continue to offer teacher workshops in CAP3 and develop new curriculum that we will disseminate through workshops and website. Through two CAP-leveraged NSF grants (Math and Science Partnership and GK-12), we will construct a course for teachers on sustainability science that will incorporate aspects of CAP research on ecosystem services.

Our student-centered programs include in-class presentations, after-school programs, and summer camps. We have partnered with Navajo Elementary School, which serves a low-income community, to advance the school's science curriculum. We installed a WeatherBug© weather station on their campus and incorporated weather studies into their curriculum design. We will continue this partnership, creating classroom-activity kits in partnership with a service-learning course developed by ASU's School of Sustainability and other education initiatives related to CAP's stormwater research. Additionally, we plan to disseminate curriculum on the urban heat island (http://k12engineering.asu.edu) that we develop in collaboration with a NSF ITEST grant, to after-school programs run by area Boys and Girls Clubs.

Scientist Training for Undergraduate and Graduate Students

Undergraduate and graduate student research, education, and mentoring are fundamental to CAP's mission (Fig. 5.1). CAP provides an excellent platform for student research, which has been instrumental in forwarding our socioecological investigations. Since 1997, our students have written over 60 theses and dissertations. Their research has been widely published in the formal literature; since 2004, students have published over 30 papers as first authors in journals such as *Frontiers in Ecology and Environment*, *BioScience*, and *Social Science Quarterly*.

Students are full members of CAP research teams and, in this capacity, are mentored by faculty members and postdoctoral research associates. CAP provides funds for graduate-student research through its grad-grant program during the academic year and summer; we funded 30 graduate students in this manner during CAP2. We will expand this program in CAP3, incorporating a peer-review system for evaluating proposals. We will issue 2 calls for proposals per year, and assemble a review panel consisting of the most recent awardees plus 1-2 faculty advisors (students will therefore only be eligible to apply for funds once per year). This system will provide valuable experience to students in conducting peer review, as well as ensuring that we engage larger numbers of students from across the three ASU campuses and other institutions with CAP participants. Students also may receive support through graduate-research assistantships (RAs) to faculty members associated with the project; the calls for short requests for these RAs are issued once per year to the CAP faculty participants. Finally, CAP faculty members will develop and teach a graduate course in ASU School of Sustainability entitled “Synthesis and Sustainable Futures,” which will explore sustainable visions and scenarios with a focus on urban ecology, drawing upon empirical research in CAP and advances in pedagogy in the scenario-planning field (e.g., Biggs et al 2010).

We promote undergraduate research through the Research Experience for Undergraduates (REU) program, which, since 2004, has involved 15 students in faculty-research projects, ranging from work on summer monsoons and carbon cycling to vegetation density and crime in urban parks. In addition, we initiated a partnership with Scottsdale Community College to involve advanced biology students in our research through field and laboratory inquiry. REU students often are co-mentored by our CAP graduate students, affording them an opportunity to learn about mentoring. A mentoring seminar is required for those students who are supervising REU students.

CAP showcases student research at its annual poster symposium, and students are encouraged to present their research at regional, national, and international meetings. Graduate students have formed an active community of urban-ecology practice, CAP Grads, which organizes activities throughout the year. CAP graduate students have also been active in the Integrative Graduate Education and Research Training (IGERT) in Urban Ecology program. Furthermore, ASU has begun a new initiative called GISER, to offer graduate students from schools and departments across the University the opportunity to engage in short-term, student-driven interdisciplinary research related to society and environment. GISER will be a primary means of advertising our semi-annual calls for grad-grant research proposals, and we will work with their leadership to build peer-review panels.

Outreach

Outreach initiatives in CAP3 will focus on formal and informal education, citizen science, and the co-production of knowledge, building upon experience garnered during CAP1 and 2 (Fig. 5.1). We have partnerships with the Chandler Environmental Education Center, the Gilbert Riparian Institute, and the McDowell Sonoran Conservancy to conduct teacher workshops and/or citizen science projects on their sites. The relationship with the Conservancy, for example, includes a formal-education initiative with teachers in the Scottsdale Unified School District, CAP research access to the McDowell Sonoran Preserve, and involvement of citizen-scientists in collecting floral and faunal data from the Preserve. Other informal-education outreach includes curriculum and teaching for summer camps at the Desert Botanical Garden and ASU’s Herberger College for Kids.

Co-production of knowledge is recognized as a critical means of affecting policy and practice, and our new synthesis and scenario research will directly exploit this opportunity. Within other elements of our project, we will work closely with the DCDC and its partner organizations to exchange knowledge in the water sector that reflects an understanding of ecosystem services, leveraging our own partnership with the City of Phoenix. Separately, we will continue to find ways to collaborate with area tribal communities on common issues; current discussions have focused on air-quality research as well as riparian restoration and stormwater management. We will continue our support of the Urban Agriculture Working Group, facilitated through ASU, which brings together researchers, practitioners, and policymakers to design and implement agricultural initiatives in desert cities. Work will continue in CAP3 with residential developers on planning research initiatives that enhance understanding of development design and ecosystem services.

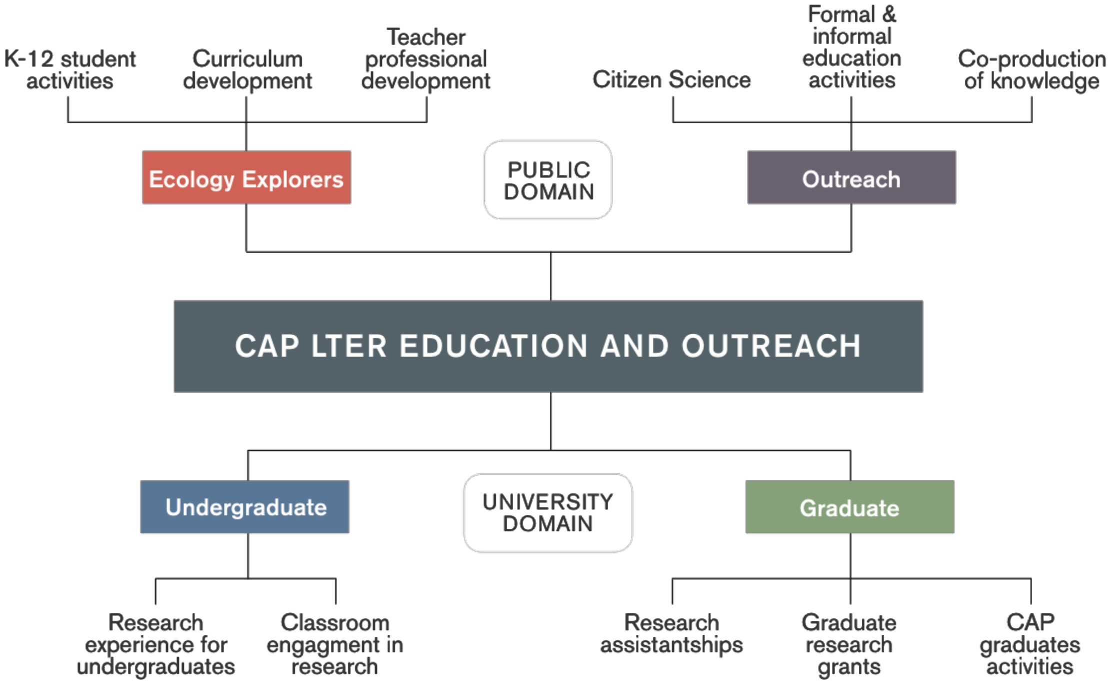


Figure 5.1. Structure of CAP3 educational and outreach activities: upper boxes are efforts in the public domain (includes governmental organization, private businesses, and non-governmental organizations), and lower boxes are efforts in the university domain (includes all ASU campuses plus institutional affiliations of CAP3 participating scientists and primarily undergraduate or primarily minority-serving institutions with REU students).

Part 6 - Literature Cited

Abbott, J., and A. Klaiber. In review. An embarrassment of riches: Confronting omitted variable bias and multi-scale capitalization in hedonic price models. (2009)

Allan, J. A. 1993. Fortunately, there are substitutes for water otherwise our hydro-political futures would be impossible. Pp. 13-26 in. *Priorities for Water Resources Allocation and Management*. ODA, London.

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

Baker, L. A., P. M. Hartzheim, S. E. Hobbie, J. Y. King and K. C. Nelson. 2007. Effect of consumption choices on fluxes of carbon, nitrogen and phosphorus through households. *Urban Ecosystems* 10: 97-117.

Bang, C., and S. H. Faeth. In review. Variation in diversity, trophic structure and abundance in response to urbanization: a decade of arthropod monitoring. *Conservation Biology*.

Banks, D. L., M. Elser, and C. Saltz. 2005. Analysis of the K-12 component of the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) project 1998 to 2002. *Environmental Education Research* 11(5):649-663.

Barnett, T. P., and D. Pierce. 2009. Sustainable water deliveries from the Colorado River in a changing climate. *Proceedings of the National Academy of Sciences* 106(18):7334-7338.

Bennett, E., G. Peterson, and L. Gordon. 2009. Understanding relationships among multiple ecosystem services. *Ecology Letters* 12(12):1394-1404.

Biggs, R., M. W. Diebel, D. Gilroy, A. M. Kamarainen, M. S. Kornis, N. D. Preston, J. E, Schmitz, C. K. Uejio, M. C. Van De Bogert, B. .C. Weidel, P. C. West, D. P. M. Zaks, and S. R. Carpenter. 2010. Preparing for the future: teaching scenario planning at the graduate level. *Front Ecol Environ* 2009; doi: 10.1890/080075.

Bolin, B., A. Nelson, E. J. Hackett, K. D. Pijawka, C. S. Smith, D. Sicotte, E. K. Sadalla, E. Matranga, and M. O'Donnell. 2002. The ecology of technological risk in a Sunbelt city. *Environment and Planning A* 34:317-339.

Bolin, B., S. Grineski, and T. Collins. 2005. Geography of despair: Environmental racism and the making of south Phoenix, Arizona, USA. *Human Ecology Review* 12 (2):155-167.

Bolte J, D. Hulse, S. Gregory, and C. Smith. 2006. Modeling biocomplexity – Agents, landscapes and alternative futures. *Environmental Modelling and Software* 22:570–579.

Boone, C. G. 2008. Environmental justice as process and new avenues for research. *Environmental Justice* 1(3):149-153.

Bradley, C. A., S. E. Gibbs, and S. Altizer. 2008. Urban land use predicts West Nile virus exposure in songbirds. *Ecol. Appl.* 18:1083-1092.

Brazel, A. J., N. Selover, R. Vose, and G. Heisler. 2000. The tale of two climates: Baltimore and Phoenix urban LTER sites. *Climate Research* 15(2):123-135.

Brazel, A., and G. Heisler. 2009. Climatology of urban Long-Term Ecological Research sites: Baltimore Ecosystem Study and Central Arizona-Phoenix. *Geography Compass* 3(1): 22-44.

Briggs, J. M., K. A. Spielmann, H. Schaafsma, K. W. Kintigh, M. Kruse, K. Morehouse, and K. Schollmeyer. 2006. Why ecology needs archaeologists and archaeology needs ecologists. *Frontiers in Ecology and the Environment* 4(4):180-188.

Brown, R. D., and T. J. Gillespie. 1995. *Microclimatic Landscape Design: Creating Thermal Comfort and Energy Efficiency*. John Wiley & Sons, New York.

Bruse, M., and H. Fleer. 1998. Simulating surface-plant-air interactions inside urban environments with a three dimensional numerical model. *Environmental Modelling and Software* 13(3-4):373-384 . doi:10.1016/S1364-8152(98)00042-5

Buizer, J., N. Beller-Simms, K. Jacobs, B. Bentzin, E. Shea, R. Anderson, and M. Roy. 2010. *Planning Integrated Research for Decision Support for Climate Adaptation and Water Management: A Focus on Desert and Coastal Cities.* Workshop Report, NOAA/ASU, Arizona State University, Tempe, AZ. 30 pp.

Burton, T. M., and G. E. Likens. 1975. Energy flow and nutrient cycling in salamander populations in Hubbard Brook Experimental Forest, New Hampshire. *Ecology* 56:1068-1080.

Buyantuyev, A., and J. Wu. 2007. Effects of thematic resolution on landscape pattern analysis. *Landscape Ecology* 22(1):7-13.

Buyantuyev, A., and J. Wu. 2009. Urbanization alters spatiotemporal patterns of ecosystem primary production: A case study of the Phoenix metropolitan region, USA. *Journal of Arid Environments* 73:512-520.

Buyantuyev, A., J. Wu, and C. Gries. 2007. Estimating vegetation cover in an urban environment based on Landsat ETM+ imagery: A case study in Phoenix. USA. *International Journal of Remote Sensing* 28(2):269-291.

Carpenter, S. R., H. Mooney, J. Agard, D. Capistrano, R. DeFries, S. Diaz, T. Dietz, A. Duraiappah, A. Oteng-Yeboah, H. Pereira, C. Perrings, W. Reid, J. Sarukhan, R. Scholas, and A. Whyte. 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences* 106(5):1305-1312.

Carreiro, M. M., and C. E. Tripler. 2005. Forest remnants along urban-rural gradients: Examining their potential for global change research." *Ecosystems* 8(5):568-582.

Center for the Future of Arizona and Gallup Poll. 2009. *The Arizona We Want*. Phoenix: Center for the Future of Arizona. Accessed at http://www.thearizonawewant.org/

Chapagain, A. K., and S. Orr. 2009. An improved water footprint methodology linking global consumption to local water resources: A case of Spanish tomatoes, *J. Enviro. Manage.* 90:1219-1228. doi:10.1016/j.jenvman.2008.06.006.

Chapin, F. S., A. Lovecraft, E. Zaveleta, J. Nelson, M. Robards, G. Kofinas, S. Trainor, G. Peterson, H. Huntington, and R. Naylor. 2006. Policy strategies to address sustainability of Alaskan boreal forests in response to a directionally changing climate. *Proceedings of the National Academy of Sciences* 103(45):16637-16643.

Cohen, J., T. Jonsson, and S. Carpenter. 2003. Ecological community description using the food web, species abundance, and body size. *Proceedings of the National Academy of Sciences* 100(4):1781-1786.

Collins, S. L., S. M. Swinton, C. W. Anderson, B. Benson, J. Brunt, T. Gragson, N. B. Grimm, M. Grove, D. Henshaw, A. K. Knapp, G. Kofinas, J. J. Magnuson, W. McDowell, J. Melack, J. C. Moore, L. Ogden, J. H. Porter, O. J. Reichman, G. P. Robertson, M. D. Smith, J. Vande Castle, and A. C. Whitmer. 2007. *Integrated Science for Society and the Environment: A Strategic Research Initiative*. Miscellaneous Publication of the LTER Network.

Cook, W. M., and S. H. Faeth. 2006. Irrigation and land use drive ground arthropod community patterns in urban desert. *Environmental Entomology* 35:1532-1540.

Costanza, R., L. Graumlich, W. Steffen, C. Crumley, J. Dearing, K. Hibbard, R. Leemans, C. Redman, and D. Schimel. 2007. Sustainability or collapse: What can we learn from integrating the history of humans and the rest of nature? *Ambio* 36(7):522-527.

Deplazes, P., D. Hegglin, S. Gloor, and T. Romig. 2004. Wilderness in the city: the urbanization of *Echinococcus multilocularis*. *Trends Parasitol.* 20:77-84.

Deviche, P., H. B. Fokidis, B. Lerbour, and E. Greiner. In press. Blood parasitaemia in a high latitude flexible breeder, the white-winged crossbill, *Loxia leucoptera*: contribution of seasonal relapse versus new inoculations. *Parasitology*. Published online by Cambridge University Press doi:10.1017/S003118200999134X.

Deviche, P., K. McGraw, and E. C. Greiner. 2005. Interspecific differences in hematozoan infection in Sonoran Desert *Aimophila* sparrows. *J. Wildl. Dis.* 41:532-541.

Deviche, P., L. Hurley, and B. Fokidis. In review. Avian testicular structure, function, and regulation. Invited book chapter *in* D. Norris, ed., *Hormones and Reproduction in Vertebrates*, Vol. 4, Academic Press.

Dresner, M., and M. Elser. 2009. Enhancing science teachers' understanding of ecosystem interactions with qualitative conceptual models. *Teaching Issues and Experiments in Ecology* Vol. 6: Research #1 [online]. http://tiee.ecoed.net/vol/v6/research/dresner/abstract.html

Dugan, L. E., M. F. Wojciechowski, and L. R. Landrum. 2007. A large scale plant survey: Efficient vouchering with identification through morphology and DNA analysis. *TAXON* 56(4):1238-1244.

El-Ashmawy, L., N. Toke, and R.J. Arrowsmith. 2009. Sedimentary geology of urban environments: An example of measuring sediment production and composition in Tempe, AZ. Geological Society of America *Abstracts with Programs* 41(7):145.

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

Fokidis, H. B., and P. Deviche. In review. Sources of variation in the hypothalamo-pituitary-adrenal axis activity of city and desert Curve-billed Thrashers *Toxostoma curvirostre*. *Journal of Experimental Biology*.

Fokidis, H. B., M. Orchinik, and P. Deviche. 2009. Corticosterone and corticosteroid binding globulin in birds: Relation to urbanization in a desert city. *General and Comparative Endrocrinology* 160(2009):259-270.

Foster, D., S. R. Carpenter, J. M. Grove, N. B. Grimm, P. Moorcroft, C. Redman, L. Schneider, T. Spies, and J. Thompson. 2009. *Future Scenarios of Land Use and Climate Change*. LTER Network Synthesis Prospectus White Paper.

Gammage, G., Jr., J. H. Hall, R. E. Lang, R. Melnick, and N. Welsch. 2008. *Megapolitan: Arizona's Sun Corridor*. Morrison Institute of Public Policy. Arizona State University. Tempe, AZ.

Gober, P., A. J. Brazel, S. Myint, R. Quay, A. Miller, S. Rossi, and S. Grossman-Clarke. 2010. Using watered landscapes to manipulate urban heat island effects: how much water will it take to cool Phoenix? *Journal of the American Planning Association* 76: 109-121.

Graf, W. L. 1975. The impact of suburbanization on fluvial geomorphology. *Water Resources Research* 11:690-693.

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

Grimm, N. B., D. Foster, P. Groffman, J.M. Grove, C. S. Hopkinson, K. Nadelhoffer, D. Peters, and D. E. Pataki. 2008b. The changing landscape: Ecosystem responses to urbanization and pollution across climatic and societal gradients. *Frontiers in Ecology and the Environment* 6(5):264-272.

Grimm, N. B., J. M. Grove, S. T. A. Pickett, and C. L. Redman. 2000. Integrated approaches to long-term studies of urban ecological systems. *BioScience* 50(7):571-584.

Grimm, N. B., S. H. Faeth, N. E. Golubiewski, C. R. Redman, J. Wu, X. Bai, and J. M. Briggs. 2008a. Global change and the ecology of cities. *Science* 319:756-760.

Grineski, S., B. Bolin, and C. Boone. 2007. Criteria air pollution and marginalized populations: Environmental inequity in metropolitan Phoenix, Arizona. *Social Science Quarterly* 88(2):535-554.

Grossman-Clarke, S, Y. Liu, J. A. Zehnder, and J. D. Fast. 2008. Simulations of the urban planetary boundary layer in an arid metropolitan area. *Journal of Applied Meteorology and Climatology* 47(3):752–768.

Guhathakurta, S., and P. Gober. 2007. The impact of the Phoenix urban heat island on residential water use. *Journal of the American Planning Association* 73(3):317-329.

Guston, D. H., and D. Sarewitz. 2002. Real-time technology assessment. *Technology in Society* 24:93-109.

Haberl, H., V. Winiwarter, K. Andersson, R. U. Ayres, C. Boone, A. Castillo, G. Cunfer, M. Fischer- Kowalski, W. R. Freudenburg, E. Furman, R. Kaufmann, F. Krausmann, E. Langthaler, H. Lotze-Campen, M. Mirtl, C. L. Redman, A. Reenberg, A. Wardell, B. Warr and H. Zechmeister. 2006. From LTER to LTSER: Conceptualizing the socioeconomic dimension of long-term socioecological research. *Ecology and Society* 11 (2):13.

Hall, S. J., B. Ahmed, P. Ortiz, R. Davies, R. Sponseller, and N. B. Grimm. 2009. Urbanization alters soil microbial functioning in the Sonoran Desert. *Ecosystems* 12(4):654-671.

Harlan, S. L., A. Brazel, L. Prashad, W. L. Stefanov, and L. Larsen. 2006. Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine* 63:2847-2863.

Harlan, S. L., A. J. Brazel, G. D. Jenerette, N. S. Jones, L. Larsen, L. Prashad, and W. L. Stefanov. 2008. In the shade of affluence: The inequitable distribution of the urban heat island. Pp. 173-202 *in* R. C. Wilkinson and W. R. Freudenburg, eds., *Equity and the Environment*, Vol. 15 of the Research in Social Problems and Public Policy Series. Elsevier, Ltd.

Harlan, S. L., M. Budruk, A. Gustafson, K. Larson, D. Ruddell, V. K. Smith, A. Wutich, and S. Yabiku. 2007**.** *Phoenix Area Social Survey 2006 Highlights: Community and Environment in a Desert Metropolis.* Central Arizona – Phoenix Long-Term Ecological Research Project Contribution No. 4. Global Institute of Sustainability, Arizona State University.

Harlan, S. L., S. Yabiku, L. Larsen, and A. Brazel. 2009**.** Household water consumption in an arid city: Affluence, affordance, and attitudes. *Society and Natural Resources* 22:691-709.

Harms, T. K., and N. B. Grimm. In press. Influence of the hydrologic regime on resource availability in a semi-arid stream-riparian corridor. *Ecohydrology*.

Harrison, C., M. Limb, and J. Burgess. 1987. Nature in the city: Popular values for a living world. *Journal of Environmental Management* 25:347-362.

Hartz, D., A. J. Brazel, and G. M. Heisler. 2006a. A case study in resort climatology of Phoenix, Arizona, USA. *International Journal of Biometeorology* 51:73-83.

Hartz, D., L. Prashad, B. C. Hedquist, J. Golden, and A. J. Brazel. 2006b. Linking satellite images and hand-held infrared thermography to observed neighborhood climate conditions. *Remote Sensing of Environment* 104:190-200.

Hedquist, B. 2005. Assessment of the urban heat island of Casa Grande, Arizona. *Journal of the Arizona-Nevada Academy of Sciences* 38(1):29-39.

Heisler, G. M.,and Y. Wang. 2002. Applications of a human thermal comfort model. Pp. 70-71 in F*ourth Symposium on the Urban Environment,* American Meteorological Society.

May 20-24, Norfolk, VA, Software available at http://www.nrs.fs.fed.us/tools/outcomes/ See also http://www.fs.fed.us/ne/syracuse/Pubs/Downloads/02_GH_YW_Applications.pdf

Hirt, P., A. Gustafson, and K. L. Larson. 2008. The mirage in the Valley of the Sun. *Environmental History* 13:482-514.

Hoekstra, A. Y., and P. Q. Hung. 2002. Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade. *Value of Water Research Report Series No.11*, Delft, Netherlands: UNESCO-IHE.

Hope, D., C. Gries, D. Casagrande, C. L. Redman, N. B. Grimm, and C. Martin. 2006. Drivers of spatial variation in plant diversity across the central Arizona-Phoenix ecosystem. *Society and Natural Resources* 19(2):101-116.

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

Hope, D., W. Zhu, C. Gries, J. Oleson, J. Kaye, N. B. Grimm, and B. Baker. 2005. Spatial variation in soil inorganic nitrogen across an arid urban ecosystem. *Urban Ecosystems* 8:251-273.

Hulse, D., A. Branscomb, C. Enright, and J. Bolte. In press. Anticipating floodplain trajectories: A comparison of two alternative futures approaches. *Landscape Ecology*.

Huste, A., and T. Boulinier. 2007. Determinants of local extinction and turnover rates in urban bird communities. *Ecol. Appl.* 17:168-180.

Jenerette, G. D., J. Wu, N. B. Grimm, and D. Hope. 2006. Points, patches and regions: Scaling soil biogeochemical patterns in an urbanized arid ecosystem. *Global Change Biology* 12:1532-1544.

Jenerette, G. D., S. L. Harlan, A. Brazel, N. Jones, L. Larsen, and W. L. Stefanov. 2007. Regional relationships between vegetation, surface temperature, and human settlement in a rapidly urbanizing ecosystem. *Landscape Ecology* 22:353-365.

Ji, M. and J. R. Jensen.1999. Effectiveness of subpixel analysis in detecting and quantifying urban imperviousness from Landsat Thematic Mapper imagery. *Geocarto International* 14(4):31– 39.

Karl, T. R., J. M. Melillo, and T. C. Peterson, eds. 2009. *Global Climate Change Impacts in the United States: A State of Knowledge Report from the U.S. Global Change Research Program.* ,New York. Cambridge University Press

Kaye, J. P., A. Majumdar, C. Gries, A. Buyantuyev, N. B. Grimm, D. Hope, G. D. Jenerette, W. Zhu, and L. Baker. 2008. Hierarchical Bayesian scaling of soil properties across urban, agricultural, and desert ecosystems. *Ecological Applications* 18:132-145.

Kaye, J. P., P. M. Groffman, N. B. Grimm, L. A. Baker, and R. Pouyat. 2006. A distinct urban biogeochemistry? *Trends in Ecology and Evolution* 21(4):192-199.

Keys, E., E. A. Wentz, and C. L. Redman. 2007. The spatial structure of land use from 1970-2000 in the Phoenix, Arizona metropolitan area. *The Professional Geographer* 59(1):L131-147.

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

Klaiber, H. A., and V. K. Smith, 2009. *Evaluating Rubin's Causal Model for Measuring the Capitalization of Environmental Amenities*. NBER Working Paper #14957. Available online at http://www.nber.org/papers/w14957

Klaiber, H. A., V. K. Smith, M. Kaminsky, and A. Strong, 2009. Measuring residential water demand under ‘data duress.’ *Water Resources Research*, invited for special section on water demand, currently unpublished working paper, September 2009.

Komiyama, H., and K. Takenchi. 2006. Sustainability science: Building a new discipline. *Sustainability Science* 1(1):1-6.

Larsen, L., and S. L. Harlan. 2006. Desert dreamscapes: Landscape preference and behavior. *Landscape and Urban Planning* 78:85-100.

Larson, E., S. Earl, E. Hagen, R. Hale, H. Hartnett, M. McCrackin, M. McHale, and N. B. Grimm. In review. Beyond restoration and into design: Hydrologic alterations in aridland cities. *In* Pickett, STA, Cadenasso, M., McGrath, B., and Hill, K., eds.,*Urban Ecological Heterogeneity and its Application to Resilient Urban Design.*

Larson, K. L., A. Gustafson, and P. Hirt. 2009b. Insatiable thirst and a finite supply: Assessing municipal water conservation policy in greater Phoenix, Arizona, 1980-2007. *Journal of Policy History* 21(2):107-137.

Larson, K. L., D. White, P. Gober, S. Harlan, and A. Wutich. 2009c. Divergent perspectives on water resource sustainability in a public-policy-science context. *Environmental Science and Policy* 12:1012-1023.

Larson, K. L., E. Cook, C. Strawhacker, and S. Hall. In review. The influence of personal values on multifaceted land management decisions in residential yards. *Human Ecology*.

Larson, K. L., S. Hall, E. Cook, B. Funke, C. Strawhacker, and V.K. Turner. 2008. *Social-Ecological Dynamics of Residential Landscapes: Human Drivers of Management Practices and Ecological Structure in an Urban Ecosystem Context.* Unpublished report from an Interdisciplinary Graduate Research and Education Training (IGERT) workshop, Global Institute of Sustainability, Arizona State University.

Larson, K., D. Casagrande, S. Harlan, and S. Yabiku. 2009a. Residents’ yard choices and rationales in a desert city: Social priorities, ecological impacts, and decision tradeoffs. *Environmental Management* 44:921-937.

Lewis, D. B., and N. B. Grimm. 2007. Hierarchical regulation of nitrogen export from urban catchments: Interactions of storms and landscapes. *Ecological Applications* 17(8):2347-2364.

Lewis, D. B., J. P. Kaye, C. Gries, A. P. Kinzig, and C. L. Redman. 2006. Agrarian legacy in soil nutrient pools of urbanizing arid lands. *Global Change Biology* 12:1-7.

Liu, J., T. Dietz, S. Carpenter, M. Alberti, C. Folke, E. Moran, A. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. Redman, S. Schneider and W. Taylor. 2007a. Complexity of coupled human and natural systems. *Science* 317:1513-1516.

Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W.Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor. 2007b. Coupled human and natural systems. *Ambio* 36(8):639-649.

Liu, Y., M. Mahmoud, H. Hartmann, S. Stewart, T. Wagener, D. Semmens, R. Stewart, H. Gupta, D. Dominguez, D. Hulse, R. Letcher, B. Rashleigh, C. Smith, R. Street, J. Ticehurst, M. Twery, H. van Delden, R. Waldick, D. White, and L. Winter. 2007. Formal scenario development for environmental impact assessment studies. *In* A. Jakeman, A. Voinov, A. E. Rizzoli, and S. Chen, eds., *State of the Art and Futures in Environmental Modelling and Software*. IDEA Book Series. Elsevier, London

Lohse, K. A., D. Hope, R.A. Sponseller, J.O. Allen, L. Baker, and N.B. Grimm. 2008. Atmospheric deposition of carbon and nutrients across an arid metropolitan area. *Science of the Total Environment* 402(2008):95-105.

Majumdar, A., C. Gries, and J. Walker. In press. A non-stationary spatial generalized linear mixed model approach for studying plant diversity. *International Journal of Statistics and Systems*.

Majumdar, A., C. Gries, J. Walker, and N. Grimm. In review. Bivariate zero-inflated regression for count data: A Bayesian model with application to plant counts. *Biometrics*.

Majumdar, A., J. P. Kaye, C. Gries, D. Hope, and N. B. Grimm. 2008. Hierarchical spatial modeling and prediction of multiple soil nutrients and carbon concentrations. *Communications in Statistics – Simulation and Computation* 37(2):434-453.

Martin, C. A. 2008. Landscape sustainability in a Sonoran Desert city. *Cities and the Environment* 1(2):article 5, 16 pp. Online at http://escholarship.bc.edu/cate/vol1/iss2/5.

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

Martin, C. A., P. S. Warren, and A. P. Kinzig. 2003b. Landscape vegetation in small urban parks and surrounding neighborhoods: Are socioeconomic characteristics a useful predictor of vegetation taxa richness and abundance? *HortScience* 38(5):733.

Marzluff, J. M., and A. D. Rodewald. 2008. Conserving biodiversity in urbanizing areas: Nontraditional views from a bird’s perspective. *Cities and the Environment* 1(2):article 6, 27 pp. http://escholarship.bc.edu/cate/vol1/iss2/6.

McAuliffe, J. 1994. Landscape evolution, soil formation, and ecological patterns and processes in Sonoran Desert bajadas. *Ecological Monographs* 64(2):111-148.

McIntyre, N. E. 2000. Ecology of urban arthropods: A review and a call to action. *Annals of the Entomological Society of America* 93(4):825-835.

McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. *Bioscience* 52(10): 883-890.

McLean, B. 2007. *Geochemical Consequences of Management on Water Resources in Central Arizona, USA*. Unpublished M.S. thesis, School of Earth and Space Exploration, Arizona State University.

MEA (Millennium Ecosystem Assessment). 2005. *Ecosystems and human well-being: Current state and trends, Vol. 1* Island Press, Washington, D.C.

Milesi, C., S. W. Running, C. D. Elvidge, J. B. Dietz, B. T. Tuttle, and R. R. Nemani. 2005. Mapping and modeling the biogeochemical cycling of turf grasses in the United States. *Environmental Management* 36: 426-438.

Myint, S. W. and G. S. Okin, 2009. Modelling land-cover types using multiple endmember spectral mixture analysis in a desert city. *International Journal of Remote Sensing* 1366-5901, 30(9):2237-2257.

Naiman, R. J., H. Decamps, and M. E. McClain. 2005. *Riparia: Ecology, Conservation, and Management of Streamside Communities*. Elsevier Academic Press. London. 430 p.

Nassauer, J. I., and R. C. Corry. 2004. Using normative scenarios in landscape ecology. *Landscape Ecology* 19:343-356.

Neil, K., and J. Wu. 2006. Effects of urbanization on plant flowering phenology: A review. *Urban Ecosystems* 9:243-257.

Neil, K., C. Bang, S. Faeth, and J. Wu. In review. Plant sex in the city: Effects of land cover on brittlebush (*Encelia farinosa*) flowering phenology and arthropod pollinator community in a desert city. *Ecology*.

Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. R. Cameron, K. M. Chan, C. G. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and R. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment* 7:4-11.

NRC (National Research Council). 1980. Urban Pest Management. Washington, D.C.: National Academy of Sciences

Oleson, J., D. Hope, C. Gries, and J. Kaye. 2006. Estimating soil properties in heterogeneous land-use patches: A Bayesian approach. *Environmetrics* 17:517-525.

Patel, M., K. Kok, and D. S. Rothman. 2007. Participatory scenario construction in land use analysis: An insight into the experiences created by stakeholder involvement in the Northern Mediterranean. *Land Use Policy* 24:546-561.

Pattison, W., and J. Vest. 2009. Sun Corridor Projections: Final Report. Economic and Demographic Forecasts to 2040. University of Arizona Eller College Of Management, Economic And Business Research Center. Report.

Pauly, D.,V. Christensen, J. Dalsgaard , R. Froese, and F. Torres, Jr. 1998. Fishing down marine food webs. *Science* 279(5352):860-863.

Peters, D. P. C., P. M. Groffman, K. J. Nadelhoffer, N. B. Grimm, S. L. Collins, W. K. Michener, and M. A. Huston. 2008. Living in an increasingly connected world: A framework for continental-scale environmental science. *Frontiers in Ecology and the Environment* 6(5):229–237.

Peterson, G. D., T. D. Beard Jr., B. E. Beisner, E. M. Bennett, S. R. Carpenter, G. S. Cumming, C. L. Dent, and T. D. Havlicek. 2003. Assessing future ecosystem services: A case study of the Northern Highlands Lake District, Wisconsin. *Conservation Ecology* 7(3):1. [online] URL: http://www.consecol.org/vol7/iss3/art1.

Phaneuf, D., V. K. Smith, R. Palmquist, and J. Pope. 2008. Integrating property value and local recreation models to value ecosystem services in urban watersheds. *Land Economics* 84(3):361-281.

Pianka, E. R. 1967. On lizard species diversity: North American flatland deserts. *Ecology* 48:332-351.

Pickett, S. T. A., C. G. Boone, and M. L. Cadenasso. 2007. Relationships of environmental justice to ecological theory. *Bulletin of the Ecological Society of America* 88(2):166-170.

Powell, B. F., and R. J. Steidl. 2002. Habitat selection by riparian songbirds breeding in southern Arizona. *The Journal of Wildlife Management* 66:1096-1103.

Pyle, R. M. 1978. The extinction of experience. *Horticulture* 56:64-67.

Quay, R. In review. Anticipatory governance: A tool for climate change adaptation. *Journal of American Planning Association* (Accepted for peer review 11/27/09).

Redman, C. L., and A. P. Kinzig. 2008. Water can flow uphill. Pp. 238-271 *in* C. L. Redman and D. R. Foster, eds. *Agrarian Landscapes in Transition: A Cross-scale Approach*. Oxford University Press.

Redman, C. L., and D. R. Foster, eds. 2008. *Agrarian Landscapes in Transition: A Cross-scale Approach*. Oxford University Press.

Redman, C. L., J. M. Grove, and L. Kuby. 2004. Integrating social science into the Long-Term Ecological Research (LTER) Network: Social dimensions of ecological change and ecological dimensions of social change. *Ecosystems* 7(2):161-171.

Rheindt, F. E. 2003. The impact of roads on birds: Does song frequency play a role in determining susceptibility to noise pollution? J*ournal für Ornithologie* 144:295-306

Roach, W. J., and N. B. Grimm. 2009. Nutrient variation in an urban lake chain and its consequences for phytoplankton production. *Journal of Environmental Quality* 38:2439-1440.

Roach, W. J., J. B. Heffernan, N. B. Grimm, J R. Arrowsmith, C. Eisinger, and T. Rychener. 2008. Unintended consequences of urbanization for aquatic ecosystems: A case study from the Arizona desert. *Bioscience* 58 (8):715-727.

Robinson, J. 2003. Future subjunctive: Backcasting as social learning. *Futures* 35, 839-856.

Ruddell, B. L. 2009. Virtual water policy (for the future of the Great Lakes). *ASCE Environmental & Water Resources Congress*, Kansas City, MO, USA, May 2009.

Ruddell, D. M., S. L. Harlan, S. Grossman-Clarke, and A. Buyantuyev. 2010. Risk and exposure to extreme heat in microclimates of Phoenix, AZ. Pp. 179-202 *in* P. Showalter and Y. Lu, eds., *Geospatial Techniques in Urban Hazard and Disaster Analysis*. Springer-Verlag, New York.

Ruddell, D., and E. A. Wentz. 2009. Multi-tasking: Scale in geography. *Geography Compass* 3(2):681-697.

Ruddell, D., S. L. Harlan, S. Grossman-Clarke, and G. Chowell. In review. Scales of perception: Analyzing local and regional perceptions of climate change. *Risk Analysis*.

Ryan, R. L. 2005. Exploring the effects of environmental experience on attachment to urban natural areas. *Environment and Behavior* 37:3-42.

Sanders, T. A., and W. D. Edge. 1998. Breeding bird community composition in relation to riparian vegetation structure in the western United States. *The Journal of Wildlife Management* 62:461-473.

Schaafsma, H., and J. M. Briggs. 2007. Hohokam silt capturing technology: Silt fields in the northern Phoenix basin. *Kiva* 72:443-469.

Schlesinger, M. D., P. N. Manley, and M. Holyoak. 2008. Distinguishing stressors acting on land bird communities in an urbanizing environment. *Ecology* 89:2302-2314.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H-P Huang, N. Harnik, A. Leetmaa, N-C Lau, C. Li, J. Velez, and N. Naik. 2007. Model projections of an imminent transition to a more arid climate in Southwestern North America. *Science* 316(5828):1181-1184.

Shen, W., J. Wu, N. B. Grimm, and D. Hope. 2008. Effects of urbanization-induced environmental changes on desert ecosystem functioning. *Ecosystems* 11:138-155.

Shen, W., J. Wu., P. R. Kemp, J. F. Reynolds, and N. B. Grimm. 2005. Simulating the dynamics of primary productivity of a Sonoran ecosystem: Model parameterization and validation. *Ecological Modelling* 189(2005):1-24.

Shochat, E., P. S. Warren, and S. H. Faeth. 2006a. Future directions in urban ecology. *Trends in Ecology and Evolution* 21(12):661-662.

Shochat, E., P. S. Warren, S. H. Faeth, N. E. McIntyre, and D. Hope. 2006b. From patterns to emerging processes in mechanistic urban ecology. *Trends in Ecology and Evolution* 21(4):186-191.

Shochat, E., S. B. Lerman, J. M Anderies, P. S. Warren, S. H. Faeth, and C. H. Nilon. In press. Invasion, competition and biodiversity loss in urban ecosystems. *BioScience*.

Shochat, E., S. Lerman, M. Katti, and D. Lewis. 2004. Linking optimal foraging behavior to bird community structure in an urban-desert landscape: Field experiments with artificial food patches. *American Naturalist* 164(2):232-243.

Shumaker, S. A., and R. B. Taylor. 1983. Toward a clarification of people-place relationships: A model of attachment to place. *In* N. R. Feimar and E. S. Geller, eds., *Environmental Psychology: Directions and Perspectives*. Praeger, New York.

Smith, V. K. 2005. Fifty years of contingent valuation. *In* A. Alberini, D. Bjornstad, and J. Kahn, eds., *Handbook of Contingent Valuation*. Edward Elgar, Cheltenhen, UK.

Snyder, S., P. Westerhoff, Y. Yoon, and D. Sedlak. 2003. Pharmaceuticals, personal care products, and endocrine disruptors in water: Implications for the Water industry. *Environmental Engineering Science* 20(5):449-469

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

Stefanov, W. L., M .S. Ramsey, and P. Christiansen. 2001. Monitoring urban land cover change: An expert system approach to land cover classification of semiarid to arid urban centers. *Remote Sensing of the Environment* 77(2):173-185.

Stuart, G., C. Gries, and D. Hope. 2006. The relationship between pollen and extant vegetation across an arid urban ecosystem and surrounding desert in the southwest USA. *Journal of Biogeography* 33:573-591.

Sun, C-Y., A. Brazel, W. T. L. Chow, B. C. Hedquist, and L. Prashad. 2009. Desert heat island study in winter by mobile transect and remote sensing techniques. *Theoretical & Applied Climatology* 98:323-335. DOI 10.1007/s00704-009-0120-2.

Swart, R. J., P. Raskin, and J. Robinson. 2004. The problem of the future: Sustainability science and scenario analysis. *Global Environmental Change* 14:137-146.

Turner II, B. L. 2009. Sustainability and forest transitions in the southern Yucatán: The land architecture approach. *Land Use Policy*21:170-180.

Turner, B. L., E. Lambin and A. Reenberg. 2007. The emergence of land change science for global environmental change and sustainability. *Proceedings, National Academy of Sciences of the United States of America* 104(52):20666-20671.

Vivoni, E. R., C. A. Aragon, L. Malczynski, and V. C. Tidwell. 2009. Numerical simulations of the impact of climate variability and change on semiarid watershed response in central New Mexico. *Hydrology and Earth System Sciences Discussions* 6: 319-371.

Vivoni, E. R., D. Entekhabi, R. L. Bras, and V. Y. Ivanov. 2007. Controls on runoff generation and scale-dependence in a distributed hydrologic model. *Hydrology and Earth System Sciences* 11(5):1683-1701.

Walker, J. S., and J. M. Briggs. 2007. An object-oriented approach to urban forest mapping with high-resolution, true-color aerial photography. *Photogrammetric Engineering and Remote Sensing* 73(5):577-583.

Walker, J. S., N. B. Grimm, J. M. Briggs, C. Gries, and L. Dugan. 2009. Effects of urbanization on plant species diversity in central Arizona. *Frontiers in Ecology and the Environment* 7(9):465-470.

Walz, A., C. Lardelli, H. Behrendt, A. Grêt-Regamey, C. Lundström, S. Kytzia, and P. Bebi. 2007. Participatory scenario analysis for integrated regional modeling. *Landscape and Urban Planning* 81:114-131.

Wang, F. 1990. Improving remote sensing image analysis through fuzzy information representation. *Photogrammetric Engineering and Remote Sensing* 56(8):1163– 1168.

Warren, P. S., M. Katti, M. Ermann, and A. Brazel. 2006. Urban bioacoustics: It's not just noise. *Animal Behaviour* 17(3):491-502.

Westerhoff, P., and J. Crittenden. 2009. Urban infrastructure and use of mass balance models for water and salt. Pp. 49-68 *in* L. Baker, ed., *The Water Environment of Cities*, Springer.

Westerhoff, P., H. Moon, H., D. Minakata, and J. Crittenden. 2009. Oxidation of organics in retentates from reverse osmosis wastewater reuse facilities. *Water Research* 43(16):3992-3998.

Westerhoff, P., S. Snyder, Y. Yoon, and E. Wert. 2005. Endocrine disruptor, pharmaceutical, and personal care product fate during simulated drinking water treatment processes. *Environmental Science and Technology* 39(17):6649-6663.

Wiek, A., and A. Walter. 2009. A transdisciplinary approach for formalized integrated planning and decision-making in complex systems. *European Journal of Operational Research* 197:360-370.

Wiek, A., C. R. Binder, and R. W. Scholz. 2006. Functions of scenarios in transition processes. *Futures* 38:740-766.

Wiek, A., D. Lang, and M. Siegrist. 2008. Qualitative system analysis as a means for sustainable governance of emerging technologies – the case of nanotechnology. *Journal of Cleaner Production* 16: 988-999.

Wiek, A., L. Gasser, and M. Siegrist. 2009. Systemic scenarios of nanotechnology – Sustainable governance of emerging technologies. *Futures* 41(5):284-300.

Wondzell, S. M., G. K. Cunningham, and D. Bachelet. 1996. Relationships between landforms, geomorphic processes, and plant communities on a watershed in the northern Chihuahuan Desert. *Landscape Ecology* 11:351-362.

Wu, J. 2008a. Toward a landscape ecology of cities: Beyond buildings, trees, and urban forests. Pp. 10-28 *in* M. M. Carreiro, Y. C. Song, and J. G. Wu, eds., *Ecology, Planning, and Management of Urban Forests: International Perspectives.* Springer Series on Environmental Management, Springer, New York. 467 pp.

Wu, J. and O. L. Loucks. 1995. From balance-of-nature to hierarchical patch dynamics: A paradigm shift in ecology. *Quarterly Review of Biology* 70:439-466.

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

Wu. J. 2008b. Landscape ecology. Pp. 2103-2109 *in* S. E. Jorgensen, ed. and B. Fath, assoc. ed., *Encyclopedia of Ecology*. Elsevier, Oxford.

Xiang, W.-N., and K. C. Clarke. 2003. The use of scenarios in land-use planning. *Environment and Planning B* 30:885-909.

Yabiku, S., D. G. Casagrande, and E. Farley-Metzger. 2008. Preferences for landscape choice in a southwestern desert city. *Environment and Behavior* 40:382-400.

York, A., C. Clark, A. Wutich, and S. Harlan. In review a. Does cheap land cause sprawl? Citizen perceptions of drivers and policy prescriptions. *Journal of the American Planning Association.*

York, A., S. N. Conley, and J. Helepololei. In review b. In land we trust: One hundred years of direct democracy on state trust land. *Political Research Quarterly*.

Zhu, W., D. Hope, C. Gries, and N. B. Grimm. 2006. Soil characteristics and the accumulation of inorganic nitrogen in an arid urban ecosystem. *Ecosystems* 9:711-724.

List of Acronyms and Abbreviations

ABI: NSF Advances in Biological Informatics program
ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASU: Arizona State University
BACI: Before-after-control-impact
BES: Baltimore Ecosystem Study LTER
BRC: NSF Biological Research Collections
CAP LTER: Central Arizona-Phoenix Long-Term Ecological Research
CDR: Cedar Creek Ecosystem Reserve LTER
CUAHSI: Consortium of Universities for the Advancement of Hydrologic Science, Inc.
DCDC: Decision Center for Desert City, Arizona State University
DMUU: NSF Decision Making Under Uncertainty program
EML: Ecological Metadata Language
EPA: Environmental Protection Agency
FCE: Florida Coastal Everglades LTER
GIOS: Global Institute of Sustainability, Arizona State University
GIS: Geographic Information Systems
GISER: Graduates in Integrative Society and Environment Research
HFC: Household Flux Calculator
IGERT: Integrative Graduate Education and Research Traineeship
IM: Information Management
INTEROP: NSF Community-based Data Interoperability Networks
IPA: Integrative Project Area
ISSE: Integrative Science for Society and Environment
IT: Information Technology
ITR: NSF Information Technology Research
JRN: Jornada Basin LTER
KNZ: Konza Prairie LTER
LIDAR: Light Detection and Ranging remote sensing technology
LNO: LTER Network Office
LTER: Long-Term Ecological Research
LUMPS: Local Scale Urban Meteorological Parameterization Scheme
LVW: Localized virtual water
MALS: Maps and Locals
MEA: Millennium Ecosystem Assessment
MM5: Mesoscale Meteorological Model
MODIS: Moderate Resolution Imaging Spectroradiometer
NAIP: National Agriculture Imagery Program
NDV: North Desert Village
NDVI: Normalized Difference Vegetation Index
NPP: Net Primary Productivity
NRC: National Research Council
NTL: North Temperate Lakes LTER
NWT: Niwot Ridge LTER
OBIA: Object Based Image Analysis
OUTCOMES: Outdoor Comfort Expert System
PASS: Phoenix Area Social Survey

PASTA: Provenance Aware SynThesis Architecture
PIE: Plum Island Ecosystems LTER
POPs: Persistent organic pollutants
PPCPs: Pharmaceutical and personal care products
REST: Representational State Transfer
REU: Research Experience for Undergraduates
RSLS: Remote Sensing Lab for Sustainability, Arizona State University
SES: Socio-Ecological System
SEV: Seviletta LTER
SGS: Short Grass Steppe LTER
TRI: Toxics Release Inventory
tRIBS: TIN-based Real-Time Integrated Basin Simulator
UHI: Urban Heat Island
UNEP: United Nations Environment Program
UVCC: Urban Vulnerability to Climate Change project, Arizona State University
XML: Extensible Markup Language

CAP LTER Products

Journal Articles

In Press

Buyantuyev, A., J. Wu, and C. Gries. In press. Multiscale analysis of the urbanization pattern of the Phoenix metropolitan landscape of USA: Time, space and thematic resolution. *Landscape and Urban Planning* doi:10.1016/j.landurbplan.2009.10.005

Davies, R., and S. J. Hall. In press. Direct and indirect effects of urbanization on soil and plant nutrients in desert ecosystems of the Phoenix metropolitan area, AZ. *Urban Ecosystems.* (2010).

Faeth, S. H., and E. Shochat. In press. Asexual microbial symbionts in a native grass shift relative abundances and species richness and evenness of associated arthropod communities. *Ecology*.

Larson, K. L., D. Ibes, and D. White. In press. Gendered perspectives on water scarcity and resource governance: A tripartite conceptual approach. *Environment and Behavior* (2009).

Majumdar, A., C. Gries, and J. Walker. In press. A non-stationary spatial generalized linear mixed model approach for studying plant diversity. *International Journal of Statistics and Systems*.

Shochat, E., S. B. Lerman, J. M Anderies, P. S. Warren, S. H. Faeth, and C. H. Nilon. In press. Invasion, competition and biodiversity loss in urban ecosystems. *BioScience*.

Singer, C. K., and C. A. Martin. In press. Effect of landscape mulches and drip irrigation on transplant establishment and growth of three North American desert native plants. *Journal of Environmental Horticulture* (2009).

Strong, A., and V. K. Smith. In press. Reconsidering the economics of demand analysis with kinked budget constraints. *Land Economics* (February 2010).

Svoma, B., and A. J. Brazel In press. The urban influence on the diurnal temperature cycle in Phoenix, Arizona, *Climate Research*.

Walker, J. S., and E. Shochat. In press. Scalar effects of urbanization and vegetation abundance on avian communities in an arid urban ecosystem. *Urban Ecosystems*.

White, D., A. Wutich, T. Lant, K. Larson, P. Gober, and C. Senneville. In press. Credibility, saliency, and legitimacy of boundary objects for environmental decision making: Water managers' assessment of WaterSim – a dynamic simulation model in an immersive decision theater. *Science and Public Policy* 37(3).

White, J. and J. Stromberg. In press. Resilience, restoration and riparian ecosystems: Case study of a dryland urban river. *Restoration Ecology*.

Wu, J., G. D. Jenerette, A. Buyantuyev, and C. L. Redman. In press. Quantifying spatiotemporal patterns of urbanization: The case of the two fastest growing metropolitan regions in the United States. *Ecological Modelling* (accepted 2009)

Wutich, A., T. Lant, D. White, K. L. Larson, and M. Gartin. In press. Comparing focus group and individual responses on sensitive topics: A study of water decision makers in a desert city. *Field Methods* 22(1).

In Review

Abbott, J. K., and H. A. Klaiber. In review. An embarrassment of riches: Confronting omitted variable bias and multi-scale capitalization in hedonic price models. *Review of Economics and Statistics*.

Aguilar, R., J. Pan, C. Gries, I. San Gil, and G. Palanisamy. In review. A flexible online metadata editing and management system. *Ecological Informatics.*

Bang, C., and S. H. Faeth. In review. Variation in diversity, trophic structure and abundance in response to urbanization: a decade of arthropod monitoring. *Conservation Biology*.

Chow, W. T. L., W_C. Chuang, and P. Gober, In review. Mapping vulnerability to extreme heat in metropolitan Phoenix: spatial, temporal and demographic dimensions. *The Professional Geographer*.

Chow, W. T. L., R. L. Pope, and A. J. Brazel, In review. Observing and modeling the nocturnal park cool island of an arid city: horizontal and vertical impacts. *Theoretical and Applied Climatology*.

Crona, B., M. Gartin, A. Wutich, and P. Westerhoff. In review. Urban ecological knowledge? Urban perceptions of water quality in a desert city. *Ecology and Society*.

Dimitrova, R., N. Lurponglukana, H.J.S. Fernando, G.C. Runger, P. Hyde, B.C. Hedquist, J. Anderson, W. Bannister, and W. Johnson. In review. Linking particulate matter (PM10) and childhood asthma in Central Phoenix. *Air Quality, Atmosphere & Health*.

Fokidis, H. B., and P. Deviche. In review. Sources of variation in the hypothalamo-pituitary-adrenal axis activity of city and desert Curve-billed Thrashers *Toxostoma curvirostre*. *Journal of Experimental Biology*.

Gober, P., C. Redman, T. Lant, and A. Wutich. In review. WaterSim: Integrated modeling, decision support and boundary science. *Population and Environment.*

Grossman-Clarke, S., J. A. Zehnder, T. Loridan, and S. C. B. Grimmond. In review. Contribution of land use changes to near surface air temperatures during recent summer extreme heat events in the Phoenix metropolitan area. *Journal of Applied Meteorology and Climatology*.

Hartz, D. A., J. S. Golden, C. Sister, W. C. Chuang, and A. J. Brazel In review. A biometeorology study of heat incidents in Chicago, Illinois. *International Journal of Biometeorology*.

Johnson J. C., P. Trubl, and V. Blackmore. In review. Male mate choice in black widows: Chemical and physical cues allow males to avoid sexual cannibalism by poor-condition females. *Proceedings of the Royal Society*.

Kaye, J. P., S. E. Eckert, D. A. Gonzales, J. O. Allen, S. J. Hall, R. A. Sponseller, and N. B. Grimm. In review. Can atmospheric carbon deposition stimulate microbial respiration in desert soils? *Journal of Environmental Quality*.

Kitchen, K., M. C. B. Andrade, and J. C. Johnson. In review. Age differences, family origin and maternal investment explain juvenile cannibalism in the black widow spider better than kin selection. *Animal Behaviour*.

Larson, K. L., E. Cook, C. Strawhacker, and S. Hall. In review. The influence of personal values on multifaceted land management decisions in residential yards. *Human Ecology*.

Lewis, D. B., J. D. Schade, and N. B. Grimm. In review. Islands of soil fertility, urbanization, and cross-scale interactions in a desert landscape. *Ecological Complexity*.

Majumdar, A., C. Gries, J. Walker, and N. Grimm. In review. Bivariate zero-inflated regression for count data: A Bayesian model with application to plant counts. *Biometrics*.

Musacchio, L., and J. Wu. In review. Developing synchronicity in urban ecology as sustainability science: Linking ecology, design, and planning. *Frontiers in Ecology and the Environment*.

Myint, S. W., A. Brazel, G. Okin, A. Buyantuyev, and W. K. Kim. In review. An interactive function of impervious and vegetation covers in relation to the urban heat island effect in a rapidly urbanizing desert city. *Sensors*.

Neil, K., C. Bang, S. Faeth, and J. Wu. In review. Plant sex in the city: Effects of land cover on brittlebush (*Encelia farinosa*) flowering phenology and arthropod pollinator community in a desert city. *Ecology*.

Neil, K., L. Landrum, and J. Wu. In review. Effects of urbanization on flowering phenology in the metropolitan Phoenix region of USA: Evidence from herbarium records. *Oecologia*

Ruddell, D., S. L. Harlan, S. Grossman-Clarke, and G. Chowell. In review. Scales of perception: Public awareness of regional and neighborhood climate change. *International Journal of Urban and Regional Research*.

Subramanya, S., B. Li, C. Gries, and H. Liu. In review. Selecting complementary features from multiple data sources for information integration. *Transactions on Systems, Man, and Cybernetics--Part C: Applications and Reviews.*

Walker, J. S., J. M. Grove, and J. M. Briggs. In review. Money grows trees: A socio-ecological path analysis. *Ecological Applications*.

York, A., A. Barnett, A. Wutich, and B. Crona. In review. Tap or bottled? A study of local environmental concern. *Environment and Behavior.*

York, A., C. Clark, A. Wutich, and S. Harlan. In review. Does cheap land cause sprawl? Citizen perceptions of drivers and policy prescriptions. *Journal of the American Planning Association*.

York, A. M., S. N. Conley, and J. Helepololei. In review. In land we trust: One hundred years of direct democracy on state trust land. *Political Research Quarterly*.

2010

Buyantuyev, A., and J. Wu. 2010. Urban heat islands and landscape heterogeneity: linking spatiotemporal variations in surface temperatures to land-cover and socioeconomic patterns. *Landscape Ecology* 25:17-33. DOI 10.1007/s10980-009-9402-4.

Gober, P., A. J. Brazel, R. Quay, S. Myint, S. Grossman-Clarke, A. Miller, and S. Rossi. 2010. Using watered landscapes to manipulate urban heat island effects: how much water will it take to cool Phoenix? *Journal of the American Planning Association* 76: 109-121.

2009

Brazel, A. and G. Heisler. 2009. Climatology of urban Long-Term Ecological Research sites: Baltimore Ecosystem Study and Central Arizona-Phoenix. *Geography Compass* 3(1):22-44.

Buyantuyev, A., and J. Wu. 2009. Urbanization alters spatiotemporal patterns of ecosystem primary production: A case study of the Phoenix metropolitan region, USA. *Journal of Arid Environments* 73:512-520.

Chen, X., and J. Wu. 2009. Sustainable landscape architecture: Implications of the Chinese philosophy of “unity of man with nature” and beyond. *Landscape Ecology* 24(8):1015-1026. DOI 10.1007/s10980-009-9350-z (online first 2009).

Cutts, B., K. Darby, C. Boone and A. Brewis. 2009. City structure, obesity, and environmental justice: An integrated analysis of physical and social barriers to walkable streets and park access. *Social Science and Medicine* 69(9):1314-1322.

Dresner, M., and M. Elser. 2009. Enhancing science teachers’ understanding of ecosystem interactions with qualitative conceptual models. *Teaching Issues and Experiments in Ecology* Vol. 6: Research #1 [online]. http://tiee.ecoed.net/vol/v6/research/dresner/abstract.html

Fokidis, H. B., M. Orchinik, and P. Deviche. 2009. Corticosterone and corticosteroid binding globulin in birds: Relation to urbanization in a desert city. *General and Comparative Endrocrinology* 160(2009):259-270.

Hall, R. O., Jr., J. L. Tank, D. J. Sobota, P. J. Mulholland, J. M. O’Brien, W. K. Dodds, J. R. Webster, H. M. Valett, G. C. Poole, B. J. Peterson, J. L. Meyer, W. H. McDowell, S. L. Johnson, S. K. Hamilton, N. B. Grimm, V. Gregory, C. N. Dahm, L. W. Cooper, L. R. Ashkenas, S. M. Thomas, R. W. Sheibley, J. D. Potter, B. R. Niederlehner, L. Johnson, A. M. Helton, C. Crenshaw, A. J. Burgin, M. J. Bernot, J. J. Beaulieu, and C. Arango. 2009. Nitrate removal in stream ecosystems measured by 15N addition experiments: total uptake. *Limnology and Oceanography* 54(3):653-665.

Hall, S. J., B. Ahmed, P. Ortiz, R. Davies, R. Sponseller, and N. B. Grimm. 2009. Urbanization alters soil microbial functioning in the Sonoran Desert. *Ecosystems* 12(4):654-671.

Harlan, S. L., S. Yabiku, L. Larsen, and A. Brazel. 2009. Household water consumption in an arid city: Affluence, affordance, and attitudes. *Society and Natural Resources* 22:691-709.

Larson, K., D. Casagrande, S. Harlan, and S. Yabiku. 2009. Residents' yard choices and rationales in a desert city: Social priorities, ecological impacts, and decision tradeoffs. *Environmental Management* 44:921-937.

Larson, K. L., A. Gustafson,, and P. Hirt. 2009. Insatiable thirst and a finite supply: Assessing municipal water conservation policy in greater Phoenix, Arizona, 1980-2007. *Journal of Policy History* 21(2):107-137.

Larson, K. L., D. White, P. Gober, S. Harlan and A. Wutich. 2009. Divergent perspectives on water resource sustainability in a public-policy-science context. *Environmental Science and Policy* 12:1012 -1023.

Marussich, W. A., and S. H. Faeth. 2009. Effects of urbanization on trophic dynamics of arthropod communities on a common desert host plant. *Urban Ecosystems* 12(3):265-286. DOI 10.1007/s11252-009-0086-y. Online first, 2009.

Mulholland, P. J., R. O. Hall, Jr., D. J. Sobota, W. K. Dodds, S. E. G. Findlay, N. B. Grimm, S. K. Hamilton, W. H. McDowell, J. M. O'Brien, J. L. Tank, L. R. Ashkenas, L. W. Cooper, C. N. Dahm, S. V. Gregory, S. L. Johnson, J. L. Meyer, B. J. Peterson, G. C. Poole, H. M. Valett, J. R. Webster, C. Arango, J. J. Beaulieu, M. J. Bernot, A. J. Burgin, C. Crenshaw, A. M. Helton, L. Johnson, B. R. Niederlehner, J. D. Potter, R. W. Sheibley, and S. M. Thomas. 2009. Nitrate removal in stream ecosystems measured by 15N addition experiments: denitrification. *Limnology and Oceanography* 54(3):666-680.

Myint, S. W., and G. S. Okin. 2009. Modeling urban land covers using multiple endmember spectral mixture analysis. *International Journal of Remote Sensing* 30 (9): 2237-2257.

Neil, K. 2009. Flowering phenology and pollination: An activity to introduce human & environmental effects on plant reproduction. *The American Biology Teacher* 71(5):300-304.

Roach, W. J., and N. B. Grimm. 2009. Nutrient variation in an urban lake chain and its consequences for phytoplankton production. *Journal of Environmental Quality* 38:2439-1440.

Ruddell, D., and E. A. Wentz. 2009. Multi-tasking: Scale in geography. *Geography Compass* 3(2):681-697.

Sun, C-Y., A. Brazel, W. T. L. Chow, B. C. Hedquist, and L. Prashad. 2009. Desert heat island study in winter by mobile transect and remote sensing techniques. *Theoretical & Applied Climatology* 98:323-335. DOI 10.1007/s00704-009-0120-2.

Walker, J. S., N. B. Grimm, J. M. Briggs, C. Gries, and L. Dugan. 2009. Effects of urbanization on plant species diversity in central Arizona. *Frontiers in Ecology and the Environment* 7(9): 465-470.

2008

Fokidis, H. B., E. C. Greiner, and P. Deviche. 2008. Interspecific variation in avian blood parasites and haematology associated with urbanization in a desert habitat. *Journal of Avian Biology* 39(3):300-310.

French, S. S., H. B. Fokidis, and M. C. Moore. 2008. Variation in stress and innate immunity in the tree lizard (*Urosaurus ornatus*) across an urban-rural gradient. *Journal of Comparative Physiology B* 178(8):997-1005.

Golden, J. S. D. Hartz, A. Brazel, G. Luber; and P. Phelan. 2008. A biometeorology study of climate and heat-related morbidity in Phoenix from 2001 to 2006. *International Journal of Biometeorology* 52(6): 471-480.

Grimm, N. B., S. H. Faeth, N. E. Golubiewski, C. R. Redman, J. Wu, X. Bai, and J. M. Briggs. 2008. Global change and the ecology of cities. *Science* 319:756-760.

Grimm, N. B., D. Foster, P. Groffman, J.M. Grove, C. S. Hopkinson, K. Nadelhoffer, D. Peters, and D. E. Pataki. 2008. The changing landscape: Ecosystem responses to urbanization and pollution across climatic and societal gradients. *Frontiers in Ecology and the Environment* 6(5):264-272.

Grossman-Clarke, S, Y. Liu, J. A. Zehnder, and J. D. Fast. 2008. Simulations of the urban planetary boundary layer in an arid metropolitan area. *Journal of Applied Meteorology and Climatology* 47(3):752–768.

Hall, S. J., D. Huber, and N. B. Grimm. 2008. Soil N_2O and NO emissions from an arid, urban ecosystem. *Journal of Geophysical Research-Biogeosciences* 113: doi:10.1029/2007JG000523.

Hirt, P., A. Gustafson, and K. L. Larson. 2008. The mirage in the Valley of the Sun. *Environmental History* 13:482-514.

Kaye, J. P., A. Majumdar, C. Gries, A. Buyantuyev, N. B. Grimm, D. Hope, G. D. Jenerette, W. Zhu, and L. Baker. 2008. Hierarchical Bayesian scaling of soil properties across urban, agricultural, and desert ecosystems. *Ecological Applications* 18:132-145.

Lohse, K. A., D. Hope, R.A. Sponseller, J.O. Allen, L. Baker, and N.B. Grimm. 2008. Atmospheric deposition of carbon and nutrients across an arid metropolitan area. *Science of the Total Environment* 402(2008):95-105.

Majumdar, A., J. P. Kaye, C. Gries, D. Hope, and N. B. Grimm. 2008. Hierarchical spatial modeling and prediction of multiple soil nutrients and carbon concentrations. *Communications in Statistics – Simulation and Computation* 37(2):434-453.

Martin, C. A. 2008. Landscape sustainability in a Sonoran Desert city. *Cities and the Environment* 1(2):article 5, 16 pp. http://escholarship.bc.edu/cate/vol1/iss2/5.

McCrackin, M. L., T. K. Harms, N. B. Grimm, S. J. Hall, and J. P. Kaye. 2008. Responses of soil microorganisms to resource availability in urban, desert soils. *Biogeochemistry* 87(2):143-155.

Miller, T. R., T. D. Baird, C. M. Littlefield, G. P. Kofinas, F. S. Chapin III, and C. L. Redman. 2008. Epistemological pluralism: Reorganizing interdisciplinary research. *Ecology and Society* 13(2):46 http://www.ecologyandsociety.org/vol13/iss2/art46/

Mulholland, P. J., A. M. Helton, G. C. Poole, R. O. Hall Jr., S. K. Hamilton, B. J. Peterson, J. L. Tank, L. R. Ashkenas, L. W. Cooper, C. N. Dahm, W. K. Dodds, S. Findlay, S. V. Gregory, N. B. Grimm, S. L. Johnson, W. H. McDowell, J. L. Meyer, H. M. Valett, J. R. Webster, C. Arango, J. J. Beaulieu, M. J. Bernot, A. J. Burgin, C. Crenshaw, L. Johnson, B. R. Niederlehner, J. M. O'Brien, J. D. Potter, R.W. Sheibley, D. J. Sobota, and S. M. Thomas. 2008. Stream denitrification across biomes and its response to anthropogenic nitrate loading. *Nature* 452:202-205.

Peters, D. P. C., P. M. Groffman, K. J. Nadelhoffer, N. B. Grimm, S. L. Collins, W. K. Michener, and M. A. Huston. 2008. Living in an increasingly connected world: A framework for continental-scale environmental science. *Frontiers in Ecology and the Environment* 6(5):229–237.

Roach, W. J., J. B. Heffernan, N. B. Grimm, J R. Arrowsmith, C. Eisinger, and T. Rychener. 2008. Unintended consequences of urbanization for aquatic ecosystems: A case study from the Arizona desert. *BioScience* 58(8):715-727.

Shao, G., and J. Wu. 2008. On the accuracy of landscape pattern analysis using remote sensing data. *Landscape Ecology* 23:505-511.

Shen, W., J. Wu, N. B. Grimm, and D. Hope. 2008. Effects of urbanization-induced environmental changes on desert ecosystem functioning. *Ecosystems* 11:138-155.

Singer, C. K., and C.A. Martin. 2008. Effect of landscape mulches on desert landscape microclimates. *Arboriculture and Urban Forestry* 34(4):230-237.

Stiles, A., and S. M. Scheiner. 2008. Nestedness of remnant Sonoran Desert plant communities in metropolitan Phoenix, Arizona. *Ecology* 89(9):2473-2481.

Walker, J. S., R. C. Balling, J. M. Briggs, M. Katti, P. Warren, and E, M. Wentz. 2008. Birds of a feather: Interpolating distribution patterns of urban birds. *Computers, Environment and Urban Systems* 32:19-28.

Walker, J. S., and T. Blaschke. 2008. Object-based land cover classification for the Phoenix metropolitan area: Optimization vs. transportability. *International Journal of Remote Sensing* 29(7):2021-2040.

Warren, P. S., S. B. Lerman and N. D. Charney. 2008. Letter to the Editor: Plants of a feather: Spatial autocorrelation of gardening practices in suburban neighborhoods. *Biological Conservation* 141(1) 3-4.

Wu, J. 2008. Changing perspectives on biodiversity conservation: From species protection to regional sustainability. *Biodiversity Science* 16(3):205-213.

Wu, J. 2008. Making the case for landscape ecology: An effective approach to urban sustainability. *Landscape Journal* 27:41-50.

Yabiku, S., D. G. Casagrande, and E. Farley-Metzger. 2008. Preferences for landscape choice in a Southwestern desert city. *Environment and Behavior* 40:382-400.

2007

Anderies, J. M,, M. Katti, and E. Shochat. 2007. Living in the city: Resource availability, predation, and bird population dynamics in urban areas. *Journal of Theoretical Biology* 247(2007):36-49.

Brazel, A., P. Gober, S.-J. Lee, S. Grossman-Clarke, J. Zehnder, B. Hedquist, and E. Comparri. 2007. Determinants of changes in the regional urban heat island in metropolitan Phoenix (Arizona, USA) between 1990 and 2004. *Climate Research* 33:171-182.

Briggs, J. M., H. Schaafsma, and D. Trenkov. 2007. Woody vegetation expansion in a desert grassland: Prehistoric human impact? *Journal of Arid Environment* 69:458-472.

Buyantuyev, A., and J. Wu. 2007. Effects of thematic resolution on landscape pattern analysis. *Landscape Ecology* 22(1):7-13.

Buyantuyev, A., J. Wu, and C. Gries. 2007. Estimating vegetation cover in an urban environment based on Landsat ETM+ imagery: A case study in Phoenix. USA. *International Journal of Remote Sensing* 28(2):269–291.

Casagrande, D. G., D. Hope, E. Farley-Metzger, W. Cook, and S. Yabiku. 2007. Problem and opportunity: Integrating anthropology, ecology, and policy through adaptive experimentation in the urban American Southwest. *Human Organization* 66(2):125-139.

Costanza, R., L. Graumlich, W. Steffen, C. Crumley, J. Dearing, K. Hibbard, R. Leemans, C. Redman, and D. Schimel. 2007. Sustainability or collapse: What can we learn from integrating the history of humans and the rest of nature? *Ambio* 36(7):522-527.

Dugan, L. E., M. F. Wojciechowski, and . L. R. Landrum. 2007. A large scale plant survey: Efficient vouchering with identification through morphology and DNA analysis. *TAXON* 56(4):1238-1244.

Grineski, S., B. Bolin, and C. Boone. 2007. Criteria air pollution and marginalized populations: Environmental inequity in metropolitan Phoenix, Arizona. *Social Science Quarterly* 88(2):535-554.

Haenn, N., and D. G. Casagrande. 2007. Citizens, experts, and anthropologists: Finding paths in environmental policy. *Human Organization* 66(2):99-102.

Janssen, M. A., J. M. Anderies, and E. Ostrom. 2007. Robustness of social-ecological systems in spatial and temporal variability. *Society and Natural Resources* 20(4):307-322.

Jenerette, G. D., S. L. Harlan, A. Brazel, N. Jones, L. Larsen, and W. L. Stefanov. 2007. Regional relationships between vegetation, surface temperature, and human settlement in a rapidly urbanizing ecosystem. *Landscape Ecology* 22:353-365.

Keys, E., E. A. Wentz, and C. L. Redman. 2007. The spatial structure of land use from 1970-2000 in the Phoenix, Arizona metropolitan area. *The Professional Geographer* 59(1):L131-147.

Lewis, D. B., and N. B. Grimm. 2007. Hierarchical regulation of nitrogen export from urban catchments: Interactions of storms and landscapes. *Ecological Applications* 17(8):2347-2364.

Li, K., P. Zhang, J. C. Crittenden, S. Guhathakurta, Y. Chen, H. Fernando, A. Sawhney, P. McCartney, N. Grimm, R. Kahhat, H. Joshi, G. Konjevod, Y. J. Choi, E. Fonseca, B. Allenby, D. Gerrity, and P. M. Torrens. 2007. Development of a framework for quantifying the environmental impacts of urban development and construction practices. *Environmental Science and Technology* 41:5130-5136.

Liu, J., T. Dietz, S. Carpenter, M. Alberti, C. Folke, E. Moran, A. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. Redman, S. Schneider and W. Taylor. 2007. Complexity of coupled human and natural systems. *Science* 317:1513-1516.

Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, Timothy Kratz, Jane Lubchenco, Elinor Ostrom, Zhiyun Ouyang, William Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor. 2007. Coupled human and natural systems. *Ambio* 36(8):639-649.

Martin C. A., K. Busse, and S. Yabiku. 2007. North Desert Village: The effect of landscape manipulation on microclimate and its relation to human landscape preferences. *HortScience* 42(4):853.

McCrackin, M. L., T. K. Harms, N. B. Grimm, S. J. Hall, and J. P. Kaye. 2007. Responses of soil microorganisms to resource availability in urban, desert soils. *Biogeochemistry* 87(2):143-155.

McDonald, R.I., C. Yuan-Farrell, C. Fievet, M. Moeller, P. Kareiva, D. Foster, T. Gragson, A. Kinzig, L. Kuby, and C. Redman. 2007. Estimating the effect of protected lands on the development and conservation of their surroundings. *Conservation Biology* 21(6):1526-1536. doi:10.1111/j.1523-1739.2007.00799.x.

Schaafsma, H., and J. M. Briggs. 2007. Hohokam silt capturing technology: Silt fields in the northern Phoenix basin. *Kiva* 72:443-469.

Sponseller, R. 2007. Precipitation pulses and soil CO_2 flux in a Sonoran Desert ecosystem. *Global Change Biology* 13:436-436.

Stiles, A., and S. M. Scheiner. 2007. Evaluation of species-area functions using Sonoran Desert plant data: Not all species-area curves are power functions. *Oikos*.116:1930-1940.

Walker, J. S., and J. M. Briggs. 2007. An object-oriented approach to urban forest mapping with high-resolution, true-color aerial photography. *Photogrammetric Engineering and Remote Sensing* 73(5):577-583.

Whitcomb, S. A., and J. C. Stutz 2007. Assessing diversity of arbuscular mycorrhizal fungi in a local community: role of sampling effort and spatial heterogeneity. *Mycorrhiza* 17:429-437.

Wu, J. 2007. Past, present and future of landscape ecology. *Landscape Ecology* 22:1433-1435.

Xu, Y., L. A. Baker, and P. C. Johnson. 2007. Trends in ground water nitrate contamination in the Phoenix, Arizona region. *Ground Water Monitoring & Remediation* 27(2):49-56.

2006

Anderies, J. M. 2006. Robustness, institutions, and large-scale change in social-ecological systems: The Hohokam of the Phoenix Basin. *Journal of Institutional Economics* 2(2):133-155.

Anderies, J. M., B. H. Walker, and A. P. Kinzig. 2006. Fifteen weddings and a funeral: Case studies and resilience-based management. *Ecology and Society* 11(1):Art. 21. Online: http://www.ecologyandsociety.org/vol11/iss1/art21/

Baker, L. 2006. Perils and pleasures of multidisciplinary research. *Urban Ecosystems* 9:45-47.

Baker, L.A., P. Westerhoff, and M. Sommerfeld. 2006. An adaptive management strategy using multiple barriers to control tastes and odors. *Journal of the American Water Works Association* 98 (6):113-126.

Briggs, J. M., K. A. Spielmann, H. Schaafsma, K. W. Kintigh, M. Kruse, K. Morehouse, and K. Schollmeyer. 2006. Why ecology needs archaeologists and archaeology needs ecologists. *Frontiers in Ecology and the Environment* 4(4):180-188.

Cook, W. M., and S. H. Faeth. 2006. Irrigation and land use drive ground arthropod community patterns in urban desert. *Environmental Entomology* 35:1532-1540.

Cumming, G. S., D. Cumming and C. L. Redman. 2006. Scale mismatches in social-ecological systems: Causes, consequences, and solutions. *Ecology and Society* 11 (1):Art. 14. Online: URL: http://www.ecologyandsociety.org/vol11/iss1/art14/

Golden, J., A. Brazel, J. Salmond, and D. Lewis. 2006. Energy and water sustainability - the role of urban climate change from metropolitan infrastructure. *Journal of Engineering for Sustainable Development* 1(1):55-70.

Haberl, H., V. Winiwarter, K. Andersson, R. U. Ayres, C. Boone, A. Castillo, G. Cunfer, M. Fischer-Kowalski, W. R. Freudenburg, E. Furman, R. Kaufmann, F. Krausmann, E. Langthaler, H. Lotze-Campen, M. Mirtl, C. L. Redman, A. Reenberg, A. Wardell, B. Warr and H. Zechmeister. 2006. From LTER to LTSER: Conceptualizing the socioeconomic dimension of long-term socioecological research. *Ecology and Society* 11 (2):13. [online] URL: http://www.ecologyandsociety.org/vol11/iss2/art13/

Harlan, S. L., A. Brazel, L. Prashad, W. L. Stefanov, and L. Larsen. 2006. Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine* 63:2847-2863.

Hartz, D., A. J. Brazel, and G. M. Heisler. 2006. A case study in resort climatology of Phoenix, Arizona, USA. *International Journal of Biometeorology* 51:73-83.

Hartz, D., L. Prashad, B. C. Hedquist, J. Golden, and A. J. Brazel. 2006. Linking satellite images and hand-held infrared thermography to observed neighborhood climate conditions. *Remote Sensing of Environment* 104:190-200.

Hope, D., C. Gries, D. Casagrande, C. L. Redman, N. B. Grimm, and C. Martin. 2006. Drivers of spatial variation in plant diversity across the central Arizona-Phoenix ecosystem. *Society and Natural Resources* 19(2):101-116.

Jenerette, G. D., W. Wu, S. Goldsmith, W. Marussich, and W. J. Roach. 2006. Contrasting water footprints of cities in China and the United States. *Ecological Economics* 57(2006):346-358.

Jenerette, G. D., J. Wu, N. B. Grimm, and D. Hope. 2006. Points, patches and regions: Scaling soil biogeochemical patterns in an urbanized arid ecosystem. *Global Change Biology* 12:1532-1544.

Kaye, J. P., P. M. Groffman, N. B. Grimm, L. A. Baker, and R. Pouyat. 2006. A distinct urban biogeochemistry? *Trends in Ecology and Evolution* 21(4):192-199.

Kirby, A., S. L. Harlan, L. Larsen, E. J. Hackett, B. Bolin, A. Nelson, T. Rex, and S. Wolf. 2006. Examining the significance of housing enclaves in the metropolitan United States of America. *Housing, Theory and Society* 23(1):19-33.

Larsen, L. and S. L. Harlan. 2006. Desert dreamscapes: Landscape preference and behavior. *Landscape and Urban Planning* 78:85-100.

Lewis, D. B., J. P. Kaye, C. Gries, A. P. Kinzig, and C. L. Redman. 2006. Agrarian legacy in soil nutrient pools of urbanizing arid lands. *Global Change Biology* 12:1-7.

Lewis, D. B., J. D. Schade, A. K. Huth, and N. B. Grimm. 2006. The spatial structure of variability in a semi-arid, fluvial ecosystem. *Ecosystems* 9:386-397.

Moeller, M., and T. Blaschke. 2006. GIS-gestützte Bildanalyse der städtischen Vegetation als ein Indikator urbaner Lebensqualität. *Photogrammetrie, Fernerkundung, Geoinformation* 2006(1):19-30.

Neil, K., and J. Wu. 2006. Effects of urbanization on plant flowering phenology: A review. *Urban Ecosystems* 9:243-257.

Oleson, J., D. Hope, C. Gries, and J. Kaye. 2006. Estimating soil properties in heterogeneous land-use patches: A Bayesian approach. *Environmetrics* 17:517-525.

Shochat, E., P. S. Warren, and S. H. Faeth. 2006. Future directions in urban ecology. *Trends in Ecology and Evolution* 21(12):661-662.

Shochat, E., P. S. Warren, S. H. Faeth, N. E. McIntyre, and D. Hope. 2006. From patterns to emerging processes in mechanistic urban ecology. *Trends in Ecology and Evolution* 21(4):186-191.

Stuart, G., C. Gries, and D. Hope. 2006. The relationship between pollen and extant vegetation across an arid urban ecosystem and surrounding desert in the southwest USA. *Journal of Biogeography* 33:573-591.

Walker, B. H., J. M. Anderies, A. P. Kinzig, and P. Ryan. 2006. Exploring resilience in socia-ecological systems through comparative studies and theory development: Introduction to the special issue. *Ecology and Society* 11(1):Art. 12. Online: http://www.ecologyandsociety.org/vol11/iss1/art12/

Warren, P. S., M. Katti, M. Ermann, and A. Brazel. 2006. Urban bioacoustics: It's not just noise. *Animal Behaviour* 17(3):491-502.

Warren P., C. Tripler, D. Bolger, S. Faeth, N. Huntly, C. Lepczyk, J. Meyer, T. Parker, E. Shochat, and J. Walker. 2006. Urban food webs: Predators, prey, and the people who feed them. *Bulletin of the Ecological Society of America* 87:386-393.

Wentz, E. A., W.L. Stefanov, C. Gries, and D. Hope. 2006. Land use and land cover mapping from diverse data sources for an arid urban environments. *Computers, Environment and Urban Systems* 30(2006):320-346.

Wu, J. 2006. Editorial: Landscape ecology, cross-disciplinarity, and sustainability science. *Landscape Ecology* 21:1-4.

Zhu, W., D. Hope, C. Gries, and N. B. Grimm. 2006. Soil characteristics and the accumulation of inorganic nitrogen in an arid urban ecosystem. *Ecosystems* 9:711-724.

2005

Albuquerque, L., C. Simoes, M. F. Nobre, N. M. Pino. J. R. Battista, M. T. Silve, F. A. Rainey and M. S. daCosta. 2005. *Truepera radiovictrix* gen. nov., sp. nov., a new radiation resistant species and the proposal of Trueperaceae fam. nov. *FEMS Microbiology Letters* 247 (2):161-169.

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

Banks, D. L., M. Elser, and C. Saltz. 2005. Analysis of the K-12 component of the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) project 1998 to 2002. *Environmental Education Research* 11(5):649-663.

Bolin, B., S. Grineski, and T. Collins. 2005. Geography of despair: Environmental racism and the making of south Phoenix, Arizona, USA. *Human Ecology Review* 12 (2):155-167.

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

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

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

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

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

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

Grossman-Clarke, S., J. A. Zehnder, W. L. Stefanov, Y. Liu, and M. A. Zoldak. 2005. Urban modifications in a mesoscale meteorological model and the effects on surface energetics in an arid metropolitan region. *Journal of Applied Meteorology* 44:1281-1297.

Hedquist, B. 2005. Assessment of the urban heat island of Casa Grande, Arizona. *Journal of the Arizona-Nevada Academy of Sciences* 38(1):29-39.

Hope, D., W. Zhu, C. Gries, J. Oleson, J. Kaye, N. B. Grimm, and B. Baker. 2005. Spatial variation in soil inorganic nitrogen across an arid urban ecosystem. *Urban Ecosystems* 8:251-273.

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

Landrum, L. R., L. Dugan, S. Whitcomb, J. Anderson, D. Damrel, and F. E. Northam. 2005. Noteworthy collections, Arizona: *Oncosiphon piluliferum* (L. f.) Kallersjo (Asteraceae). *Madroño* 52: 270-274.

Larson, E. K., N. B. Grimm, P. Gober, and C. L. Redman. 2005. The paradoxical ecology and management of water in the Phoenix, USA metropolitan area. *Journal of Ecohydrology and Hydrobiology* 5(4):287-296.

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

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

Nguyen, M. L., P. Westerhoff, L. A. Baker, M. Esparza-Soto, Q. Hu, and M. Sommerfeld. 2005. Characteristics and reactivity of algae-produced dissolved organic carbon..*Journal of Environmental Engineering* 131:1574-1582.

Rainey, F. A., K. Ray, M. Ferreira, B. Z. Gatz, N. F. Nobre, D. Bagaley, B. A. Rash, M.-J. Park, A. M. Earl, N. C. Shank, A. Small, M. C. Henk, J. R. Battista, P. Kaempfer, and M. S. Da Costa. 2005. Extensive diversity of ionizing-radiation-resistant bacteria recovered from Sonoran Desert soil and description of nine new species of the genus *Delnococcus* obtained from a single soil sample. *Applied and Environmental Microbiology* 71:5225-5235.

Redman, C. L., and N. S. Jones. 2005. The environmental, social, and health dimensions of urban expansion. *Population and Environment* October(2005):1-16.

Shen, W., J. Wu., P. R. Kemp, J. F. Reynolds, and N. B. Grimm. 2005. Simulating the dynamics of primary productivity of a Sonoran ecosystem: Model parameterization and validation. *Ecological Modelling* 189(2005):1-24.

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

Stefanov, W.L., and M. Netzband. 2005. Assessment of ASTER land cover and MODIS NDVI data at multiple scales for ecological characterization of an arid urban center. *Remote Sensing of Environment, ASTER Special Issue* 99(1-2):31-43.

2004

Berling-Wolff, S., and J. Wu. 2004. Modeling urban landscape dynamics: A review. *Ecological Research* 19:119-129.

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

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

Burns, E. K., and G. Bey. 2004. City of Phoenix and Arizona State University map water Features with GIS and GPS. *Underground Focus* 18(3):12-13.

Celestian, S. B., and C. A. Martin. 2004. Rhizosphere, surface, and under tree canopy air temperature patterns at parking lots in Phoenix, AZ. *Journal of Arboriculture* 30(4):245-251.

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

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

Hawkins, T. W., A. Brazel, W. L. Stefanov, W. Bigler, and E. M. Saffell. 2004. The role of rural variability in urban heat island determination for Phoenix, Arizona. *Journal of Applied Meteorology* 43(3):476-486.

Hope, D., M. W. Naegeli, A. H. Chan, and N. B. Grimm. 2004. Nutrients on asphalt parking surfaces in an urban environment. *Water Air & Soil Pollution: Focus* 4:371-390.

Jenerette, G. D., and J. Wu. 2004. Interactions of ecosystem processes with spatial heterogeneity in the puzzle of nitrogen limitation. *Oikos* 107(2):273-282.

Katti, M., and P. S. Warren. 2004. Research focus: Tits, noise, and urban bioacoustics. *Trends in Ecology and Evolution* 19(3):109-110.

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

Li, H., and J. Wu. 2004. Use and misuse of landscape indices. *Landscape Ecology* 19:389-399.

Martin, C. A., and L. B. Stabler. 2004. The relationship of homeowner practices and carbon acquisition potential of landscape plants to mesic and xeric designed Southwest residential landscapes. *Acta Horticulturae* 630:137-141.

Martin, C. A., and L. B. Stabler. 2004. Urban horticultural ecology: Interactions between plants, people and the physical environment. *Acta Horticulturae* 639:97-101.

Martin, C. A., and J. C. Stutz. 2004. Interactive effects of temperature and arbuscular mycorrhizal fungi on growth, P uptake and root respiration of *Capsicum annuum* L. *Mycorrhiza* 14(4):241-244.

Martin, C. A., P. S. Warren, and A. P. Kinzig. 2004. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, Arizona. *Landscape and Urban Planning* 69(4):355-368. Available online: http://www.sciencedirect.com/science/article/B6V91-4B7D8N0-1/2/b1086f9449042f1ac6f02e83b80b2888

Mash, H., M. L. Nguyen, P. K. Westerhoff, L. A. Baker, and R. Neiman. 2004. Dissolved organic matter in Arizona reservoirs: end member analysis. *Organic Geochemistry* 35:831-843.

Musacchio, L. R., J. Ewan, and R. Yabes. 2004. Regional landscape system protection in the urbanizing desert Southwest: Lessons from the Phoenix metropolitan region, U.S.A. *Landscape Review* 10(1&2):58–68.

Musacchio, L., and J. Wu. 2004. Collaborative landscape-scale ecological research: Emerging Trends in urban and regional ecology. Special Issue of *Urban Ecosystems* 7:175-178.

Quay, R. 2004. Bridging the gap between ecological research and land use policy: The North Sonoran collaboration. *Urban Ecosystems* 7:283-294.

Redman, C. L., J. M. Grove, and L. Kuby. 2004. Integrating social science into the Long-Term Ecological Research (LTER) Network: Social dimensions of ecological change and ecological dimensions of social change. *Ecosystems* 7(2):161-171. Online First: http://0-www.springerlink.com.library.lib.asu.edu:80/link.asp?id=xre6r5q9f0bnf50p

Shen, W., G. D. Jenerette, J. Wu, and R. H. Gardner. 2004. Evaluating empirical scaling relations of pattern metrics with simulated landscapes. *Ecography* 27:459-469.

Shochat, E. 2004. Credit or debit? Resource input changes population dynamics of city-slicker birds. *Oikos* 106(3):622-626.

Shochat E., S. Lerman, M. Katti, and D. Lewis. 2004. Linking optimal foraging behavior to bird community structure in an urban-desert landscape: Field experiments with artificial food patches. *American Naturalist* 164(2):232-243.

Shochat, E., W. L. Stefanov, M. E. A. Whitehorse, and S. Faeth. 2004. Urbanization and spider diversity: Influences of human modification of habitat structure and productivity. *Ecological Applications* 14(4):268-280.

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

Wu, J. 2004. Effects of changing scale on landscape pattern analysis: Scaling relations. *Landscape Ecology* 19:125-138.

Wu, J. 2004. Key research topics in landscape ecology. *Acta Ecologica Sinica* 24(9):2074-2076.

Zhu, W.-X., N. D. Dillard, and N. B. Grimm. 2004. Urban nitrogen biogeochemistry: Status and processes in green retention basins. *Biogeochemistry* 71:177-196.

Books

2009

Wu, J., and J. Yang, eds. 2009. *Lectures in Modern Ecology (IV): Theory and applications.* Higher Education Press, Beijing.

2008

Carreiro, M. M., Y-C. Song, and J. Wu, eds. 2008. *Ecology, Planning, and Management of Urban Forests: International Perspectives.* Springer Series on Environmental Management, Springer, New York. 467 pp.

Redman, C. L., and D. R. Foster, eds. 2008. *Agrarian Landscapes in Transition: A Cross-scale Approach*. Oxford University Press.

2007

Netzband, M., W. L. Stefanov, and C. Redman, eds. 2007. *Applied remote sensing for urban planning, governance and sustainability.* Springer-Verlag, Berlin Heidelberg.

Wu, J. and R. Hobbs, eds. 2007. *Key topics and perspectives in landscape ecology*. Cambridge University Press.

2006

Wu, J., B. Jones, H. Li, and O. L. Loucks, eds. 2006. *Scaling and uncertainty analysis in ecology*. Springer, Dordrecht, The Netherlands. 351 pp.

Book Chapters

In Press

Bigelow, S. W., J. J. Cole, H. Cyr, L. L. Janus, A. P. Kinzig, J. F. Kitchell, G. E. Likens, K. H. Reckhow, D. Scavia, D. Soto, L. M. Talbot, and P. H. Templer. In press. The role of models in ecosystem management. In *Understanding ecosystems: The role of quantitative models in observation, synthesis, and prediction*. Princeton University Press.

Heisler, G. M. and A. J. Brazel. In press. The urban physical environment: temperature and urban heat islands. Chapter in ASA Book on *Urban Ecosystem Ecology*.

Jenerette, G., and J. Wu. In press. Quantitative measures and ecological hierarchy. *In* L. Kapustka, W. Landis, and A. Johnson, eds., *Environmental risk assessment and management from a landscape perspective*. John Wiley & Sons. (2010)

Kinzig, A.P. In press. On the benefits and limitations of prediction. In press. In *Understanding ecosystems: The role of quantitative models in observation, synthesis, and prediction*. Princeton University Press.

Klaiber, H. A., and V. K. Smith. In press. Preference heterogeneity and non-market benefits: the roles of structural hedonic and sorting models. *In* J Bennett, ed., *The International Yearbook of Non-Market Valuation.* Edward Elgar, Cheltenham, U.K.

Lepczyk, C. A., P. S. Warren, L. Machabée, A. P. Kinzig, and A. Mertig. In press. Who feeds the birds? A comparison between Phoenix, Arizona and southeastern Michigan. *In* C. Marti, C. Lepczyk, and P. Warren, *Studies in Avian Biology: New Directions in Urban Bird Research*, Cooper Ornithological Society.

Musacchio, L. In press. Pattern and process metaphors for metropolitan landscapes. *In* M. J. McDonnell, A. K. Hahs, and J. Breuste, eds., *Ecology of Cities and Towns: A Comparative Approach*. Cambridge University Press, New York.

Rands, G., B. Ribbens, D. Casagrande, and H. McIlvaine-Newsad. In press. *Organizations and the sustainability mosaic: Crafting long-term ecological and societal solutions*. Edward Elgar.

Redman, C. L., M. Nelson and A. Kinzig. In press. The resilience of socio-ecological landscapes: Lessons from the Hohokam. *In* Fisher, C., J. Hill, and J. Fienman, eds., *The Socio-Natural Connection: Integrating Archaeology and Environmental Studies*. University of Arizona Press, Tucson.

Ruddell, D. M., S. L. Harlan, S. Grossman-Clarke, and A. Buyantuyev. In press. Risk and exposure to extreme heat in microclimates of Phoenix, AZ. *In* P. Showalter and Y. Lu, eds., *Geospatial Contributions to Urban Hazard and Disaster Analysis.* Springer.

Sih, A., A. Bell, and J. C. Johnson. In press. Behavioral syndromes: A multi-variate approach to behavioral ecology. Solicited chapter *in* D. F. Westneat and C. W.Fox, eds., *Evolutionary Behavioral Ecology*, Oxford University Press.

Smith, V. K. In press. Pre-positioned policy as public adaptation to climate change. *In* R. J. Kopp, M. Macauley, and R. Morgenstern, eds., *Adapting to Climate Change: The Public Policy Response*. Resources for the Future, Washington, D.C.

Stefanov, W. L., and M. Netzband. In press. Characterization and monitoring of urban/peri-urban ecological function and landscape structure using satellite data. *In* Jürgens, C., and Rashed, T. (eds.), *Remote sensing of urban and suburban areas*, Kluwer Academic Publishers.

Walker, B., M. Anderies, G. Peterson, A. Kinzig, and S. Carpenter. In press. Robustness in ecosystems. In *A Repertoire of Robustness*. A Santa Fe Institute Lecture Note Series, Oxford University Press.

Warren, P. S., S. L. Harlan, C. Boone, S. B. Lerman, E. Shochat and A. P. Kinzig. In press. Urban ecology and human social organization. In K. J. Gaston, ed., *Urban Ecology*. Cambridge University Press and the British Ecological Society.

In Review

Deviche, P., L. Hurley, and B. Fokidis. In review. Avian testicular structure, function, and regulation. Invited book chapter *in* D. Norris, ed., *Hormones and Reproduction in Vertebrates*, Vol. 4, Academic Press.

Grossman-Clarke, S. and W. L. Stefanov. In review. Urban weather, climate and air quality modeling: Increasing resolution and accuracy using improved landscape characterization. *In* X. Yang, ed., *Urban Remote Sensing: Monitoring, Synthesis and Modeling in the Urban Environment.*

Larson, E., S. Earl, E. Hagen, R. Hale, H. Hartnett, M. McCrackin, M. McHale, and N. B. Grimm. In review. Beyond restoration and into design: Hydrologic alterations in aridland cities. In S. T. A. Pickett, M. Cadenasso, B. McGrath, and K. Hill, eds., *Urban ecological heterogeneity and its application to resilient urban design.*

Wutich, A., and C. Gravlee. In review. Water decision makers in a desert city: Text analysis and environmental social science. *In* I. Vaccaro, E. Smith, and S. Aswani, eds., *Society and Environment: Methods and Research Design.* Cambridge University Press.

2009

Bills, R. J. and J. C. Stutz. 2009. AMF associated with indigenous and non indigenous plants at urban and desert sites in Arizona. Pp. 207-220 *in* C. Azcón-Aguilar, J. M. Barea, S. Gianinazzi, and V. Gianinazzi-Pearson, eds., *Mycorrhizas - Functional Processes and Ecological Impact*. Springer-Verlag, Heidelberg.

McIntyre, N. E., and J. J. Rango. 2009. Arthropods in urban ecosystems: Community patterns as functions of anthropogenic land use. Pp. 233-242 *in* M. McDonnell, A. Hahs, and J. Breuste, eds., *Ecology of Cities and Towns: A Comparative Approach*. Cambridge University Press, New York.

Wentz, E. A., W. L. Stefanov, M. Netzband, M. S. Moller, and A. Brazel. 2009. The urban environmental monitoring/100 cities project: Legacy of the first phase and next steps. Pp. 191-204 *in* P. Gamba and M. Herold, eds., *Global Mapping of Human Settlement, Experiences, Datasets, and Prospects.* CRC Press, Boca Raton, London, NY.

Westerhoff, P., and J. Crittenden. 2009. Urban infrastructure and use of mass balance models for water and salt. Pp. 49-68 *in* L. Baker, ed., *The Water Environment of Cities*, Springer.

Wu, J. 2009. Ecological dynamics in fragmented landscapes. *In* S. A. Levin, ed., S. R. Carpenter, H. C. J. Godfray, A. P. Kinzig, M. Loreau, J. B. Losos, B. Walker and D. S. Wilcove, assoc. eds., *Princeton Guide to Ecology*. Princeton University Press, Princeton.

2008

Brazel, A. 2008. Urban climate. *In* W. A. Dando, ed., *Climate Change and Variation: A Primer for Teachers, Vol. 1,* National Council on Geographic Education.

Harlan, S. L., A. J. Brazel, G. D. Jenerette, N. S. Jones, L. Larsen, L. Prashad, and W. L. Stefanov. 2008. In the shade of affluence: The inequitable distribution of the urban heat island. Pp. 173-202 *in* R. C. Wilkinson and W. R. Freudenburg, eds., *Equity and the Environment*, Vol. 15 of the Research in Social Problems and Public Policy Series. Elsevier, Ltd.

Marsalek, J., E. Larson, and E. Day. 2008. Strategies, policies and regulations integrating protection and rehabilitation of aquatic habitats in urban water management. Pages 25-42 *in* I. Wagner, J. Marsalek, and P. Breil, eds., *Aquatic Habitats in Sustainable Urban Water Management: Science, Policy and Practice*. UNESCO Publishing - Taylor & Francis Group, The Netherlands.

Redman, C. L. 2008. Introduction. Pp. 3-15 *in* C. L. Redman and D. R. Foster, eds. *Agrarian Landscapes in Transition: A Cross-Scale Approach*. Oxford University Press.

Redman, C. L., and A. P. Kinzig. 2008. Water can flow uphill. Pp. 238-271 *in* C. L. Redman and D. R. Foster, eds. *Agrarian Landscapes in Transition: A Cross-scale Approach*. Oxford University Press.

Wu. J. 2008. Landscape ecology. Pp. 2103-2109 *in* S. E. Jorgensen, ed. and B. Fath, assoc. ed., *Encyclopedia of Ecology*. Elsevier, Oxford.

Wu, J. 2008. On scholarship and universities of the future. Pp. 2-8 *in* B. Gu et al., eds., *Green Careers*. Higher Education Press, Beijing.

Wu, J. 2008. Toward a landscape ecology of cities: Beyond buildings, trees, and urban forests. Pp. 10-28 *in* M. M. Carreiro, Y. C. Song, and J. G. Wu, eds., *Ecology, Planning, and Management of Urban Forests: International Perspectives.* Springer Series on Environmental Management, Springer, New York. 467 pp.

2007

Baker, L. A., and P. L. Brezonik. 2007. Ecosystem approaches to reduce pollution in cities.. *In*: V. Novotny and P. Brown, eds., *Cities of the Future: Towards Integrated Sustainable Water and Landscape Management*. IWA Publishing, London.

Briel, P., N. B. Grimm, and P. Vervier. 2007. Surface water-groundwater exchange processes in fluvial ecosystems: An analysis of temporal and spatial scale dependency. *In* P. J. Wood, D. M. Hannah, and J. P. Salder, eds., *Hydroecology and Ecohydrology: Past, Present and Future*. John Wiley and Sons, Chichester, England.

Hobbs, R., and J. Wu. 2007. Perspectives and prospects of landscape ecology. Pp. 3-8 *in* J. Wu and R. Hobbs, eds., *Key topics in landscape ecology*, Cambridge University Press, Cambridge.

Li, H., and J. Wu. 2007. Landscape pattern analysis: Key issues and challenges. Pp. 39-61 *in* J. Wu and R. Hobbs, eds., *Key topics in landscape ecology*, Cambridge University Press, Cambridge.

Netzband, M., W. L. Stefanov, and C. L. Redman. 2007. Chapter 1 - Remote sensing as a tool for urban planning and sustainability. Pp. 1-23 *in* M. Netzband, W. L. Stefanov, and C. Redman, eds., *Applied remote sensing for urban planning, governance and sustainability.* Springer-Verlag, Berlin Heidelberg.

Stefanov, W. L., and A. J. Brazel. 2007. Chapter 6 - Challenges in characterizing and mitigating urban heat islands – a role for integrated approaches including remote sensing. Pp. 117-135 *in* M. Netzband, W. L. Stefanov, and C. Redman, eds., *Applied remote sensing for urban planning, governance and sustainability*. Springer-Verlag, Berlin Heidelberg.

Stefanov, W. L., M. Netzband, M. S. Möller, C. L. Redman, and C. Mack. 2007. Chapter 7 - Phoenix, Arizona, USA: Applications of remote sensing in a rapidly urbanizing desert region. Pp. 137-164 *in* M. Netzband, W. L. Stefanov, and C. Redman, eds., *Applied remote sensing for urban planning, governance and sustainability.* Springer-Verlag, Berlin Heidelberg.

Wu, J. 2007. Scale and scaling: A cross-disciplinary prospective. Pp. 115-142 *in* J. Wu and R. Hobbs, eds., Key topics in landscape ecology, Cambridge University Press, Cambridge.

Wu., J., and R. Hobbs. 2007. Landscape ecology: The state-of-the-science. Pp. 271-287 *in* J. Wu and R. Hobbs, eds., *Key topics in landscape ecology*, Cambridge University Press, Cambridge.

2006

Anderies, J. M., B. H. Walker, and A. P. Kinzig. 2006. Fifteen weddings and a funeral: Case studies and resilience-based management. Pp. 163-176 *in* B. H. Walker, J. M. Anderies, A. P. Kinzig, and P. Ryan, eds., *Exploring Resilience in Social-Ecological Systems: Comparative Studies and Theory Development*. CSIRO Publishing, Collingwood, Australia.

Cumming, G. S., D. Cumming and C. L. Redman 2006. Scale mismatches in social-ecological systems: Causes, consequences, and solutions. Pp. 23-40 *in* B. H. Walker, J. M. Anderies, A. P. Kinzig, and P. Ryan, eds., *Exploring Resilience in Social-Ecological Systems: Comparative Studies and Theory Development*. CSIRO Publishing, Collingwood, Australia.

Kinzig, A. P., and C. L. Redman. 2006. Phoenix, Arizona, USA. Pp. 191-192 *in* B. H. Walker and R. L. Lawson, *Case studies in resilience: Fifteen social ecological systems across continents and societies.* Pp. 177-192 *in* B. H. Walker, J. M. Anderies, A. P. Kinzig, and P. Ryan, eds., *Exploring Resilience in Social-Ecological Systems: Comparative Studies and Theory Development*. CSIRO Publishing, Collingwood, Australia.

Li, H., and J. Wu. 2006. Uncertainty analysis in ecological studies: An overview. Pp. 45-66 *in* J. Wu., H. Li, and O. Loucks, eds., *Scaling and uncertainty analysis in ecology.* Columbia University Press, New York.

Redman, C. L. 2006. Urban land-use patterns: Past, present, and future. Pp. 65-70 *in* J. L. Hantman and R. Most, eds., *Managing Archaeological Data: Essays in Honor of Sylvia Gaines*. Anthropological Research Papers No. 52, Arizona State University, Tempe.

Reynolds, J. F., P. R. Kemp, K. Ogle, R. J. Fernandez, Q. Gao, and J. Wu. 2006. Modeling the unique attributes of dryland ecosystems. Pp. 321-353 *in* L. F. Huenneke, K. M. Havstad, and W. H. Schlesinger, eds., *Structure and function of a Chihuahuan Desert ecosystem*, Oxford University Press, Oxford, UK.

Walker, B. H., J. M. Anderies, A. P. Kinzig, and P. Ryan. 2006. Introduction. Pp.1-4 *in* B. H. Walker, J. M. Anderies, A. P. Kinzig, and P. Ryan, eds., *Exploring Resilience in Social-Ecological Systems: Comparative Studies and Theory Development*. CSIRO Publishing, Collingwood, Australia.

Wu, J., and H. Li. 2006. Perspectives and methods in scaling: A review. Pp. 17-44 *in* J. Wu., H. Li, and O. Loucks, eds., *Scaling and uncertainty analysis in ecology.* Springer, Dordrecht, The Netherlands. 351 pp.

Wu, J., and H. Li. 2006. Concepts of scale and scaling. Pp. 3-15 *in* J. Wu., H. Li, and O. Loucks, eds., *Scaling and uncertainty analysis in ecology.* Springer, Dordrecht, The Netherlands. 351 pp.

Wu, J., H. Li, B. Jones, and O. Loucks. 2006. Scaling with known uncertainty: A synthesis. Pp. 329-346 *in* J. Wu, B. Jones, H. Li and O.L. Loucks, eds., *Scaling and uncertainty analysis in ecology*. Springer, Dordrecht, The Netherlands. 351 pp.

2005

Redman, C. L. 2005. The urban ecology of metropolitan Phoenix: A laboratory for interdisciplinary study. Pp. 163-192 in National Research Council, *Population, Land Use, and Environment: Research Directions*. Panel on New Research on Population and Environment. B. Entwisle and P. C. Stern, eds. Committee on the Human Dimensions of Global Change, Division of Behavioral Sciences and Education, The National Academies Press, Washington, D.C.

2004

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

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

Theses and Dissertations

In Progress

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. 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).

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).

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).

Hale, Rebecca. Landscape configuration controls on nutrient transport and retention in urban ecosystems (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).

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, A. Wiek).

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

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).

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

Schaasfma, Hoski. Environmental legacies of ancient farming in the Sonoran Desert (Ph.D., Plant Biology, J. Briggs).

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).

Zhuo, Xiaoding. Distribution, transport, and sources of trace elements in soils of an urban arid region (Ph.D., Chemistry and Biochemistry, E. Shock).

Completed

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., Department of 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., Geological Sciences, 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., Geological Sciences, 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., Geological Sciences, J R. Arrowsmith).

Other Publications

In Press

Townsend, A.R., L.A. Martinelli, and N.B. Grimm. In press. Perspectives on the modern nitrogen cycle. *Ecological Applications.*

2009

Larson, K. L., E. Cook, M. Grove, C. Polsky, R. R. Chowdhury, L. Ogden, N. Grimm, P. Groffman, J. Harrington, and J. Zimmerman. 2009. *Investigating the Social-Ecological Dynamics of Residential Landscapes: Insights from a Multi-Site Collaborative Workgroup.* Final Report from LTER Workshop in February 18-19, 2009. Global Institute of Sustainability.

Larson, K. L., E. Cook, S. Hall, B. Funke, and V. K. Turner. 2009. *Social-Ecological Dynamics of Residential Landscapes: Human Drivers of Management Practices and Ecological Structure in an Urban Ecosystem Context.* Final Report from an Interdisciplinary Graduate Workshop in Fall 2008. Global Institute of Sustainability.

2008

Gries, C., and M. Jones, eds. 2008. *Proceedings of the Environmental Information Management Conference 2008* (EIM 2008) September 10-11, 2008 Albuquerque, NM. http://www.lulu.com/content/paperback-book/proceedings-of-the-environmental-information-management-2008-conference-(eim-2008)/3822310

2007

Harlan, S., M. Budruk, A. Gustafson, K. Larson, D. Ruddell, V. K. Smith, A. Wutich, and S. Yabiku. 2007. *Highlights from the 2006 Phoenix Area Social Survey: Community and Environment in a Desert Metropolis*. Global Institute of Sustainability, Arizona State University, Tempe.

2006

Grimm, N.B. 2006. Ecology 2020. A message from the President. Annual Report, Ecological Society of America, Washington, D.C.

Grimm, N.B., A. Covich, and J.M. Melillo. 2006. A vision for ecology's future: Where are we today? *Frontiers in Ecology and the Environment* 4:115.

Hartz, D. A., and A. J. Brazel. 2006. The impact of the urban heat island on frosts and freezes in Phoenix, Arizona, USA. *Proceedings of the Sixth International Conference on Urban Climate, International Association for Urban Climate* (World Meteorological Organization), Goteborg, Sweden, 594-597.

2005

Hope, D., C. Gries, P. Warren, M. Katti, G. Stuart, J. Oleson, and J. Kaye. 2005. How do humans restructure the biodiversity of the Sonoran Desert? Pp. 189-194 in *Proceedings: Connecting Mountain Islands and Desert Seas: Biodiversity and Management of the Madrean Archipelago II*. 2004 May 11-15, Tucson, AZ. USDA Forest Service RMRS-P-26, Fort Collins, CO.

Melillo, J.M., N.B. Grimm, and W.H. Schlesinger. 2005. Ecology and the transition to sustainability. *Frontiers in Ecology and the Environment* 3:3.

Melillo, J.M., N.B. Grimm, and A. Covich. 2005. NEON: Lighting the way forward. *Frontiers in Ecology and the Environment* 3:351.

Walker, J. S., and J. M. Briggs. 2005. An object-oriented classification of an arid urban forest with true-color aerial photography. In *Proceedings of the ISPRS WG VII/1 Human Settlements and Impact Analysis 3rd International Symposium Remote Sensing and Data Fusion over Urban Areas (URBAN 2005) and 5th International Symposium Remote Sensing of Urban Areas (URS 2005),* March 14-16, 2005, Tempe, AZ.

2004

Burns, E. K., and G. Bey. 2004. Spatial technologies for management of water collection and distribution. In *Proceedings of Conference 27 Geospatial Information & Technology Association (GITA)*, Seattle, WA.

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

Hartz, D., A. J. Brazel, and G. M. Heisler. 2004. A case study in resort climatology of Phoenix, Arizona, USA. In Preprint volume of 22-27 August 2004 *5th Symposium on the Urban Environment*, American Meteorological Society,Vancouver, BC, Canada.

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

Lee, S.M., S. Grossman-Clarke, and H. J. S. Fernando. 2004. Some issues related to the simulation of contaminant distribution in complex-terrain areas. January 2004, *Proceedings of 85th AMS Annual Meeting,* San Diego, CA.

Machabée, L. 2004. Investigating the principles of justice in the actors' decision-making process: A case study of an urban ecological restoration project. August 23-27 2004, *16th International Annual Meeting of the Society for Ecological Restoration*, Victoria, British Colombia.

Netzband , M., and W. L. Stefanov. 2004. Urban land cover and spatial variation observation using ASTER and MODIS satellite image data. *The International Archives of the Photogrammetry, Remote Sensing, and Spatial Information Sciences* 35(B7).

Stefanov, W. L., L. Prashad, C. Eisinger, A. Brazel, and S. L. Harlan. 2004. Investigation of human modifications of landscape and climate in the Phoenix, Arizona metropolitan area using MASTER data. *The International Archives of the Photogrammetry, Remote Sensing, and Spatial Information Sciences* 35(B7):1339-1347.

List of Datasets Currently Available Online

Active Projects

Aquatic Core Monitoring (Continuation of NAWQA) (NU8)
Longterm Water Monitoring
Longterm Water Monitoring: Sites

Atmospheric Deposition (NU_31)
Atmospheric Deposition HNO3 Dry Deposition Fluxes in 1998
Atmospheric Deposition Monitoring, Sites
Atmospheric Deposition NO Dry Deposition Fluxes in 1998
Atmospheric Deposition NO2 Dry Deposition Fluxes in 1998
Atmospheric Deposition Total Nitrogen from Dry Deposition in 1998
Long term Atmospheric Deposition Monitoring

Database of Geographic Information (DB1_1)
2000 Annual Precipitation
2001 Annual Precipitation
2002 Annual Precipitation
2003 Annual Precipitation
2004 Annual Precipitation
2005 Annual Precipitation
Average precipitation in April in Central Arizona
Average precipitation in August in Central Arizona
Average precipitation in December in Central Arizona
Average precipitation in February in Central Arizona
Average precipitation in January in Central Arizona
Average precipitation in July in Central Arizona
Average precipitation in June in Central Arizona
Average precipitation in March in Central Arizona
Average precipitation in May in Central Arizona
Average precipitation in November in Central Arizona
Average precipitation in October in Central Arizona
Average precipitation in September in Central Arizona
Database of Geographic Information: A point coverage of cities, towns and villages in Arizona.
Database of Geographic Information: Aspect 30_utm
Database of Geographic Information: Canals in the Phoenix metropolitan area
Database of Geographic Information: Change in groundwater level, 1985-2000
Database of Geographic Information: County Boundaries
Database of Geographic Information: Hill shade, of the 1:250000 scale Digital Elevation Model of Arizona
Database of Geographic Information: Hydrologic unit code areas
Database of Geographic Information: Integrated data layers of Public Land Survey, land ownership and county data
Database of Geographic Information: Landownership Information Summary
Database of Geographic Information: Riparian Vegetation
Database of Geographic Information: Topographic Map of Central Arizona

Database of Geographic Information: USGS 1:24000 quadrangle boundaries
Database of Geographic Information: USGS 240k quadrangle boundaries for State of Arizona
Database of Geographic Information: slope30_utm
Digital Elevation Model (AZ 250,000:1)
Digital Elevation Model (AZ 7.5 - Minute)
Mean Annual Precipitation
Monthly maximum air temperature in April (6 year mean) in Central Arizona
Monthly maximum air temperature in August (6 year mean) in Central Arizona
Monthly maximum air temperature in December (6 year mean) in Central Arizona
Monthly maximum air temperature in February (5 year mean) in Central Arizona
Monthly maximum air temperature in January (5 year mean) in Central Arizona
Monthly maximum air temperature in July (6 year mean) in Central Arizona
Monthly maximum air temperature in June (6 year mean) in Central Arizona
Monthly maximum air temperature in March (6 year mean) in Central Arizona
Monthly maximum air temperature in May (6 year mean) in Central Arizona
Monthly maximum air temperature in November (6 year mean) in Central Arizona
Monthly maximum air temperature in October (6 year mean) in Central Arizona
Monthly maximum air temperature in September (6 year mean) in Central Arizona
Monthly minimum air temperature in April (6 year mean) in Central Arizona
Monthly minimum air temperature in August (6 year mean) in Central Arizona
Monthly minimum air temperature in December (6 year mean) in Central Arizona
Monthly minimum air temperature in February (5 year mean) in Central Arizona
Monthly minimum air temperature in January (5 year mean) in Central Arizona
Monthly minimum air temperature in July (6 year mean) in Central Arizona
Monthly minimum air temperature in June (6 year mean) in Central Arizona
Monthly minimum air temperature in March (6 year mean) in Central Arizona
Monthly minimum air temperature in May (6 year mean) in Central Arizona
Monthly minimum air temperature in November (6 year mean) in Central Arizona
Monthly minimum air temperature in October (6 year mean) in Central Arizona
Monthly minimum air temperature in September (6 year mean) in Central Arizona
Ozone concentrations in 2003
Ozone concentrations in 2004
Ozone concentrations in 2005
Three year average ozone concentrations

Decoupled Biogeochemical Cycles: Ecological Response to C and N Deposition from the Urban Atmosphere (120)
Atmospheric deposition sampling across an urban gradient, using passive resin collectors

Ecology Explorers (ED_13)
Ecology Explorers: Bird Dataset
Ecology Explorers: Bruchid Dataset
Ecology Explorers: Vegetation Dataset

Effects of the Urban Atmosphere on the Structure and Functioning of Soil Lichen Communities (173)
Ozone concentrations in 2003
Ozone concentrations in 2004

Ozone concentrations in 2005
Three year average ozone concentrations

Environmental Risk and Justice (HU_32)
Environmental Risk and Justice: Facilities 1990 locations from Toxic Release Inventory
Environmental Risk and Justice: Facilities 1990 with Toxic Release Inventory data
Environmental Risk and Justice: Facilities 1995 with Toxic Release Inventory data
Environmental Risk and Justice: Facilities 1995 with Toxic Release Inventory data in 1970 tracts
Environmental Risk and Justice: Facilities 2000 with Toxic Release Inventory data
Environmental Risk and Justice: Facilities 2000 with Toxic Release Inventory data in 1970 tracts
Environmental Risk and Justice: Locations of the facilities releasing toxic substances 1995

Growth Effects on *Encelia farinosa* (brittlebush) due to Suppression of Arbuscular Mycorrhizal Fungi at an Urban and a Desert Site. (114)
Mycorrhizal diversity and effect on brittlebush in a Sonoran Desert urban ecosystem

Historical Land Use Database (LU_19)
Historical Land Use Database: Landuse at one square mile around the survey 200 plots 1980
Historical Land Use Database: Landuse at one square mile around the survey 200 plots 1990
Historical Land Use Database: Landuse at one square mile around the survey 200 plots 2000
Land use change 1912 to 1995
Landuse Classification 1934
Landuse Classification 1955
Landuse Classification 1975
Landuse Classification 1995
Landuse Classification 2000

Institutional Drivers of Growth in Phoenix (293)
Institutional Drivers of Growth in Phoenix

Land use effects on Urban Tree Primary Productivity (PP_58)
Longterm monitoring of primary productivity of trees
Longterm monitoring of primary productivity of trees: Sites

Lichen Resurvey with Heavy Metal Analysis (PO11/NU9)
Lichen Resurvey with Heavy Metal Analysis in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Antimony concentration in lichen tissue in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Cadmium concentration in lichen tissue in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Chromium concentration in lichen tissue in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Copper concentration in lichen tissue in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Dysprosium concentration in lichen tissue in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Lead concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Nickel concentration in lichen tissue in

Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Palladium concentration in lichen tissue in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Platinum concentration in lichen tissue in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Praseodymium concentration in lichen tissue in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Tin concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Zinc concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of industiral lead emissions in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of industrial nickel emissions in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of industrial zinc emissions in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of intustrial chromium emissions in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of intustrial copper emissions in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Sites

Longterm Monitoring of Ground Arthropod Biodiversity (PO6_10)
Longterm Monitoring of Ground Arthropod Biodiversity, 1998 - 2002
Longterm Monitoring of Ground Arthropod Biodiversity, 2003 - 2008
Longterm Monitoring of Ground Arthropod Biodiversity: Sites

LTREB: Long-Term Climate Variability and Ecosystem Response in a desert stream (266)
Climate data for stations near Sycamore Creek research site
Discharge data from USGS gage near Sycamore Creek research site
Sycamore Creek macroinvertebrate collections after flooding event
Water quality at Sycamore Creek research site

Multi-Temporal Remote-Sensing Data Acquisition for CAP LTER Land Cover/Land Use Monitoring and Modeling (GE_20)
False Color Landsat Image of Greater Phoenix
Land cover classification using ASTER data - year 2000
Land cover classification using Landsat (MSS) data - year 1973
Land cover classification using Landsat (MSS) data - year 1979
Land cover classification using Landsat Enhanced Thematic Mapper (ETM) data - year 2000
Land cover classification using Landsat Enhanced Thematic Mapper (ETM) data - year 2005
Land cover classification using Landsat Thematic Mapper (TM) data - year 1985
Land cover classification using Landsat Thematic Mapper (TM) data - year 1985
Land cover classification using Landsat Thematic Mapper (TM) data - year 1990
Land cover classification using Landsat Thematic Mapper (TM) data - year 1991
Land cover classification using Landsat Thematic Mapper (TM) data - year 1993
Land cover classification using Landsat Thematic Mapper (TM) data - year 1995
Land cover classification using Landsat Thematic Mapper (TM) data - year 1998

NDVI (Normalized Difference Vegetation Index) of the 2005 Landsat Thematic Mapper Image
NDVI (Normalized difference vegetation index) Image of 1975 Landsat MSS Image
NDVI (Normalized difference vegetation index) Image of 1980 Landsat MSS Image
NDVI (Normalized difference vegetation index) Image of 1985 Landsat Thematic Mapper Image
NDVI (Normalized difference vegetation index) Image of 1993 Landsat Thematic Mapper Image
NDVI (Normalized difference vegetation index) Image of 1998 Landsat Thematic Mapper Image
NDVI (Normalized difference vegetation index) Image of 2000 Enhanced Landsat Thematic Mapper Image
SAVI (Modified Soil Adjusted vegetation index) Image of 2003 ASTER image
SAVI (Soil Adjusted Vegetation Index) Image of 1975 Landsat MSS Image
SAVI (Soil Adjusted Vegetation Index) Image of 1980 Landsat MSS Image
SAVI (Soil Adjusted Vegetation Index) Image of 1985 Landsat Thematic Mapper Image
SAVI (Soil Adjusted Vegetation Index) Image of 1990 Landsat Thematic Mapper Image
SAVI (Soil Adjusted Vegetation Index) Image of 1993 Landsat Thematic Mapper Image
SAVI (Soil Adjusted Vegetation Index) Image of 2000 Enhanced Landsat Thematic Mapper(ETM) Image
SAVI (Soil Adjusted Vegetation Index) of the 2005 Landsat Thematic Mapper Image

Nutrient Transport and Retention in Urban Watersheds (NU_44)
Indian Bend Wash Floodplain 1
Indian Bend Wash GIS Clip Output
Indian Bend Wash GIS CoverDOQQ
Indian Bend Wash GIS GRID1935
Indian Bend Wash GIS GRID1972
Indian Bend Wash GIS GRID1978
Indian Bend Wash GIS GRID1987
Indian Bend Wash GIS GRID1997
Indian Bend Wash GIS GRID2000
Indian Bend Wash GIS Lake Layer
Indian Bend Wash GIS Lake V Layer
Indian Bend Wash GIS Mask II
Indian Bend Wash GIS Park Turf II Layer
Indian Bend Wash GIS Parks Studied
Indian Bend Wash GIS Watershed Canal Union
Indian Bend Wash Parks GIS
Indian Bend Wash Problem Zones
Indian Bend Wash Stream Guages
Indian Bend Wash Vegetation GIS Layer
Indian Bend Wash Watershed cliped GIS

Nutrients and Data Synthesis, Mass Balance (NU7)
Nutrients and Data Synthesis, Mass Balance: Gila-Salt Watershed boundary
Nutrients and Data Synthesis, Mass Balance: Phoenix Dairy Farms
Nutrients and Data Synthesis, Mass Balance: Phoenix Stockyard Locations
Nutrients and Data Synthesis, Mass Balance: Phoenix citrus groves
Nutrients and Data Synthesis, Mass Balance: Phoenix crops
Nutrients and Data Synthesis, Mass Balance: Phoenix crops
Nutrients and Data Synthesis, Mass Balance: shed_agr

Phoenix Area Social Survey (HU_41)
PASS II project study sites
Phoenix Area Social Survey (PASS)
Phoenix Area Social Survey I, Sites

Point Count Bird Censusing (PO_34)
Point Count Bird Censusing
Point Count Bird Censusing: Sites

Survey 200 (PO_27)
Assessing Biodiversity of Arbuscular Mycorrhizal Fungi
Assessing Biodiversity of Arbuscular Mycorrhizal Fungi: Mycorrhiza Sites
Distribution of Ragweed Pollen sampled in Greater Phoenix
Hierarchical Spatial Modeling of Multiple Soil Nutrients and Carbon in Heterogeneous Land-Use Patches of the Phoenix Metropolitan Area
Survey 200
Survey 200 - Human activity related measurements
Survey 200 - Pollen
Survey 200 - Shrubs
Survey 200 - Soil
Survey 200 - Trees
Survey 200 Annuals
Survey 200 Arthropod Sweepnet Samples
Survey 200 Cacti
Survey 200 Historic Landuse
Survey 200 Land Use
Survey 200 Neighborhood Characteristics
hierarchical Bayesian scaling of soil properties across urban, agricultural, and desert ecosystem

Completed Projects

A High-Resolution Urban Forest Classification System for Phoenix (PP_67)
Urban forest classification based on 1997 Landiscor aerial photo

Arbuscular Mycorrhizal Fungal diversity and functioning in urban desert remnants and surround deserts (300)
Arbuscular mycorrhizal fungal diversity and functioning in urban desert preserves and surrounding deserts

Assessments of Urban Tree Health in the Phoenix Urban Ecosystem (155)
Tree health analysis in the Phoenix Metropolitan Area

Canal Study (NU_35)
Canal Study GRID 1962

Century-Scale Channel Change (GE1_5)
Century-scale Channel Change: Photographs of selected reaches of the Salt River in different years since mid 1940s
Century-scale Channel Change: Sites

CO2 Levels, Meteorological Conditions, Human Activity, and Ecosystem Processes in Urban Phoenix (336)
Afternoon transect data for modelling spatial patterns and determinants of atmospheric carbon dioxide concentrations in Phoenix metro area
Morning transect data for modelling spatial patterns and determinants of atmospheric carbon dioxide concentrations in Phoenix metro area
Spatial Patterns and Determinants of Atmospheric Carbon Dioxide Concentrations in Phoenix metro area

Comparison among Residential Patch Transition Types; Before-After (OM_14)
Water Use and Flooding in Phoenix: Comparison of water and carbon dioxide uptake by selected plant species among residential patch transition types

Dissolved Organic Carbon Dynamics in an Urban Desert Stream Ecosystem (NU_80)
Dissolved organic carbon dynamics in an urban desert stream ecosystem
Dissolved organic carbon dynamics in an urban desert stream ecosystem: Sites

Ecological and Social Interactions in Urban Parks (PP_52)
Ecological and Social Interactions in Urban Parks: Bird surveys in local parks in the CAP-LTER study area
Ecological and Social Interactions in Urban Parks: Sites

Ecophysical and Behavioral Adaptations of Birds to Rapid Urbanization of a Desert Environment (324)
Ecophysiological and behavioral adaptations of birds to rapid urbanization of a desert environment. How do Phoenix metro area birds adapt to urbanization?

Effects of Surface Mulches on Abiotic Processes of Drip-Irrigated Xeric Landscapes (86)
Effects of Surface Mulches on Abiotic Properties of Drip-Irrigated Xeric Landscapes

Effects of Urban Horticulture on Insect Pollinator Community Structure (PO_26)
Effects of Urban Horticulture on Insect Pollinator Community Structure
Effects of Urban Horticulture on Insect Pollinator Community Structure: Sites

Effects of Urbanization on the Landscape Pattern and Ecosystem Processes in the Phoenix Metropolitan Region: A Multiple-Scale Study (LU_79)
2000 Annual Precipitation
2001 Annual Precipitation
2002 Annual Precipitation
2003 Annual Precipitation
2004 Annual Precipitation
2005 Annual Precipitation
Average precipitation in April in Central Arizona

Average precipitation in August in Central Arizona
Average precipitation in December in Central Arizona
Average precipitation in February in Central Arizona
Average precipitation in January in Central Arizona
Average precipitation in July in Central Arizona
Average precipitation in June in Central Arizona
Average precipitation in March in Central Arizona
Average precipitation in May in Central Arizona
Average precipitation in November in Central Arizona
Average precipitation in October in Central Arizona
Average precipitation in September in Central Arizona
End of second growth period in 2004-2005 (Day of Year)
End of the first growth period in 2001-2002 (Day of Year)
End of the first growth period in 2002-2003 (Day of Year)
End of the first growth period in 2003-2004 (Day of Year)
End of the first growth period in 2004-2005 (Day of Year)
End of the second growth period in 2001-2002 (Day of Year)
End of the second growth period in 2002-2003 (Day of Year)
End of the second growth period in 2003-2004 (Day of Year)
Length of the first growth period in 2001 (Number of days)
Length of the first growth period in 2002 (Number of days)
Length of the first growth period in 2003 (Number of days)
Length of the first growth period in 2004 (Number of days)
Length of the first growth period in 2005 (Number of days)
Length of the second growth period in 2001 (Number of days)
Length of the second growth period in 2002 (Number of days)
Length of the second growth period in 2003 (Number of days)
Length of the second growth period in 2004 (Number of days)
Length of the second growth period in 2005 (Number of days)
Mean Annual Precipitation
Monthly maximum air temperature in April (6 year mean) in Central Arizona
Monthly maximum air temperature in August (6 year mean) in Central Arizona
Monthly maximum air temperature in December (6 year mean) in Central Arizona
Monthly maximum air temperature in February (5 year mean) in Central Arizona
Monthly maximum air temperature in January (5 year mean) in Central Arizona
Monthly maximum air temperature in July (6 year mean) in Central Arizona
Monthly maximum air temperature in June (6 year mean) in Central Arizona
Monthly maximum air temperature in March (6 year mean) in Central Arizona
Monthly maximum air temperature in May (6 year mean) in Central Arizona
Monthly maximum air temperature in November (6 year mean) in Central Arizona
Monthly maximum air temperature in October (6 year mean) in Central Arizona
Monthly maximum air temperature in September (6 year mean) in Central Arizona
Monthly minimum air temperature in April (6 year mean) in Central Arizona
Monthly minimum air temperature in August (6 year mean) in Central Arizona
Monthly minimum air temperature in December (6 year mean) in Central Arizona
Monthly minimum air temperature in February (5 year mean) in Central Arizona
Monthly minimum air temperature in January (5 year mean) in Central Arizona
Monthly minimum air temperature in July (6 year mean) in Central Arizona
Monthly minimum air temperature in June (6 year mean) in Central Arizona

Monthly minimum air temperature in March (6 year mean) in Central Arizona
Monthly minimum air temperature in May (6 year mean) in Central Arizona
Monthly minimum air temperature in November (6 year mean) in Central Arizona
Monthly minimum air temperature in October (6 year mean) in Central Arizona
Monthly minimum air temperature in September (6 year mean) in Central Arizona
Rate of greening during the first growth period in 2001-2002
Rate of greening during the first growth period in 2002-2003
Rate of greening during the first growth period in 2003-2004
Rate of greening during the first growth period in 2004-2005
Rate of greening during the second growth period in 2001-2002
Rate of greening during the second growth period in 2002-2003
Rate of greening during the second growth period in 2003-2004
Rate of greening during the second growth period in 2004-2005
Rate of senescing during the first growth period in 2001-2002
Rate of senescing during the first growth period in 2002-2003
Rate of senescing during the first growth period in 2003-2004
Rate of senescing during the first growth period in 2004-2005
Rate of senescing during the second growth period in 2002-2003
Rate of senescing during the second growth period in 2003-2004
Rate of senescing during the second growth period in 2004-2005
Start of the first growth period in 2001-2002 (Day of Year)
Start of the first growth period in 2002-2003 (Day of Year)
Start of the first growth period in 2003-2004 (Day of Year)
Start of the first growth period in 2004-2005 (Day of Year)
Start of the second growth period in 2001-2002 (Day of Year)
Start of the second growth period in 2002-2003 (Day of Year)
Start of the second growth period in 2003-2004 (Day of Year)
Start of the second growth period in 2004-2005 (Day of Year)
Total number of growth periods in the period 2001-2005

Greater Phoenix Regional Atlas (GP2100)
Regional E-Atlas of the Greater Phoenix Region: Concentration of nitrate in well water, 2000
Regional E-Atlas of the Greater Phoenix Region: Distribution of prices of single family homes, new and resale throughout the region in 2001
Regional E-Atlas of the Greater Phoenix Region: Estimated concentrations of ozone in the Greater Phoenix
Regional E-Atlas of the Greater Phoenix Region: GP2100 study area extent
Regional E-Atlas of the Greater Phoenix Region: High-Tech employment clusters
Regional E-Atlas of the Greater Phoenix Region: PM10 concentration in Greater Phoenix area
Regional E-Atlas of the Greater Phoenix Region: Particulate Matter (2.5) pollution contours
Regional E-Atlas of the Greater Phoenix Region: Percent of population by zipcode, admitted to hospitals and diagnosed with Asthma
Regional E-Atlas of the Greater Phoenix Region: Population change

Historic Records of Climate in Valley (GE_16)
Historic Records of Climate in Valley: 50 year climate data summary for the Phoenix metropolitan area

Inorganic Nutrient Dynamics in the Lower Indian Bend Wash watershed (205)
Indian Bend Wash Floodplain 1
Indian Bend Wash GIS Clip Output
Indian Bend Wash GIS CoverDOQQ
Indian Bend Wash GIS GRID1935
Indian Bend Wash GIS GRID1972
Indian Bend Wash GIS GRID1978
Indian Bend Wash GIS GRID1987
Indian Bend Wash GIS GRID1997
Indian Bend Wash GIS GRID2000
Indian Bend Wash GIS Lake Layer
Indian Bend Wash GIS Lake V Layer
Indian Bend Wash GIS Mask II
Indian Bend Wash GIS Park Turf II Layer
Indian Bend Wash GIS Parks Studied
Indian Bend Wash GIS Watershed Canal Union
Indian Bend Wash Parks GIS
Indian Bend Wash Problem Zones
Indian Bend Wash Stream Gauges
Indian Bend Wash Vegetation GIS Layer
Indian Bend Wash Water Chemistry
Indian Bend Wash Watershed clipped GIS

Land Use Effects on Temperature and Humidity along a Urban-Rural Transect Gradient (LU_49)
Land Use Effects on Temperature and Humidity along a Urban-Rural Transect Gradient
Land Use Effects on Temperature and Humidity along a Urban-Rural Transect Gradient: CO2 concentration
Quickbird Image August 11, 2005, Multiband
Quickbird Image August 11, 2005, Panchromatic

Landscape Water Use Efficiency (PP_51)
Landscape Water Use Efficiency

Microbial Degradation of Non-Point Carbon Deposition in Urban Soil (312)
Environmental Fate of Combustion-Derived Organic Compounds in Arid, Urban Soils

Modeling Urban Impervious Surface Areas in Relation to Urban Heat Island Effects (156)
Spectrally unmixed percent impervious surface, soil, and vegetation cover in CAPLTER

Mycorrhizae in an Experimental Urban Landscaped site (125)
Mycorrhizae in an Experimental Urban Landscaped Site

Nitrogen Trace Gas Emission in Urban Patches (NU_73)
Soil N2O and NO emissions from an arid, urban ecosystem

Nutrient Deposition Measurements in the CAP LTER Study Area (170)
Atmospheric deposition sampling across an urban gradient, using passive resin collectors
Ozone concentrations in 2003
Ozone concentrations in 2004
Ozone concentrations in 2005
Three year average ozone concentrations

Plant Flowering Phenology in the Phoenix Metropolitan Area (178)
Effects of land cover and water availability on brittlebush (Encelia farinosa) flowering phenology and its pollinator community.

Plant Survey of Current Vegetation (PO13+_11)
Plant Survey of Current Vegetation: Desert Vegetation
Plant Survey of Current Vegetation: Desert Vegetation, Sites
Plant Survey of Current Vegetation: MAP OF SONORAN DESERT PLANT COMMUNITY DISTRIBUTION IN MOUNTAIN PARKS OF THE CAPLTER STUDY AREA, PHOENIX, ARIZONA
Plant Survey of Current Vegetation: MAP OF SONORAN DESERT PLANT COMMUNITY DISTRIBUTION IN THE CAPLTER STUDY AREA, PHOENIX, ARIZONA

Riparian Carbon and Nitrogen Cycling: Influences of Spatial Heterogeneity and Hydrologic Vectors (335)
Riparian Carbon and Nitrogen Cycling: Influences of Spatial Heterogeneity and Hydrologic Vectors

Runoff and Throughfall Measurements in an Urban and Desert Remnant Habitat (131)
Throughfall

Scorpions in Urban Environments (PO_25)
Scorpions in Urban Environments
Scorpions in Urban Environments: Sites

Spatial Interpolation of Avian Counts (127)
Point Count Bird Censusing Data Subset for Paper 'EFFECTS OF LAND USE AND VEGETATION COVER ON BIRD COMMUNITIES' Walker et. al

Spatial/Temporal Change of Climate/Air Quality in Relation to Urban Fringe Development (LU_37)
Spatial/Temporal Change of Climate in Relation to Urban Fringe Development

Stormwater Transport of Nutrients and Metals (NU_74)
Hierarchical regulation of nitrogen export from urban catchments: Interactions of storms and landscapes.

Transect Bird Survey with Data Synthesis (PO12_12)
Transect Bird Survey with Data Synthesis

Trophic Structure and Dynamics Experiment (PO_62)
Effects of land cover and water availability on brittlebush (Encelia farinosa) flowering phenology and its pollinator community.

Urban Fringe Morphology (LU9_3)
Urban Fringe Morphology: City of Phoenix Sewer Features
Urban Fringe Morphology: City of Phoenix Sewer Lines
Urban Fringe Morphology: City of Phoenix Sewer Nodes

Urban Heat Island (264)
Urban Heat Island

Urban Raptor Project (188)
Urban Raptor Nest Study

Urban Storm Runoff (NU_28)
Urban Storm Runoff
Urban Storm Runoff: Sites

Using Leaves as Samplers to Determine the Spatial Distribution of Atmospheric Particles (NU_53)
Atmospheric Particles on mesquite leaves

Vertebrate Species Composition of Remnant Desert Islands within Urban Phoenix (PO_23)
Vertebrate Species Composition of Remnant Desert Islands within Urban Phoenix
Vertebrate Species Composition of Remnant Desert Islands within Urban Phoenix: Sites

List of Letters of Collaboration

- Navajo Elementary School
- McDowell Sonoran Conservancy
- Chandler Environmental Education Center
- Decision Center for a Desert City, ASU
- Decision Theater, ASU
- Arizona Foundation for Resource Education
- Dr. Tirupalavanam Ganesh, Mary Lou Fulton Graduate School of Education, ASU
- Gilbert Riparian Institute
- Desert Botanical Garden