Watering Grass in the Desert

Can a Phoenix Change Its Colour?

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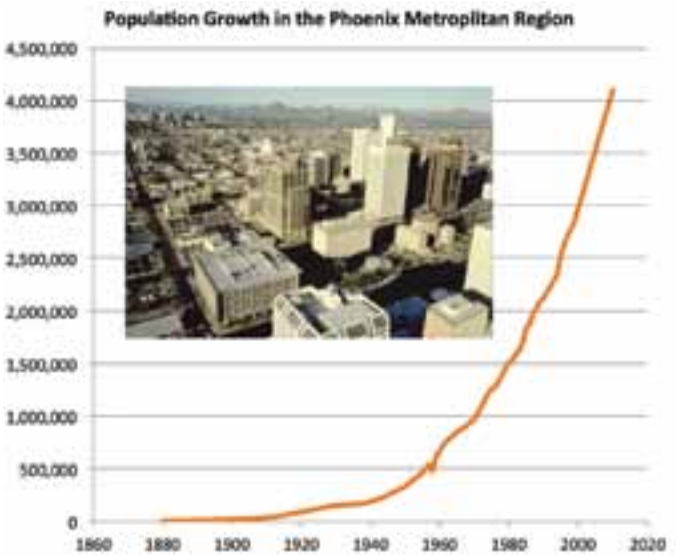
Images as credited

1. A landscape view of the Sonoran desert, including Saguaro cacti (Photo: Jingle Wu).

2. Rapid population growth with increasing urbanisation in the Phoenix area during the past several decades (Image: CAP-LTER).



2 Population Growth in the Phoenix Metroplitan Region

"If Phoenix could become sustainable, then it could be done anywhere ... Even if it is not the world's least sustainable city, it is a very close contender ... More than any other U.S. metropolis in the postwar period, Phoenix has channeled the national appetite for unrestrained growth ..."

—Andrew Ross, *Bird on Fire* (USA: Oxford University Press, 2011)

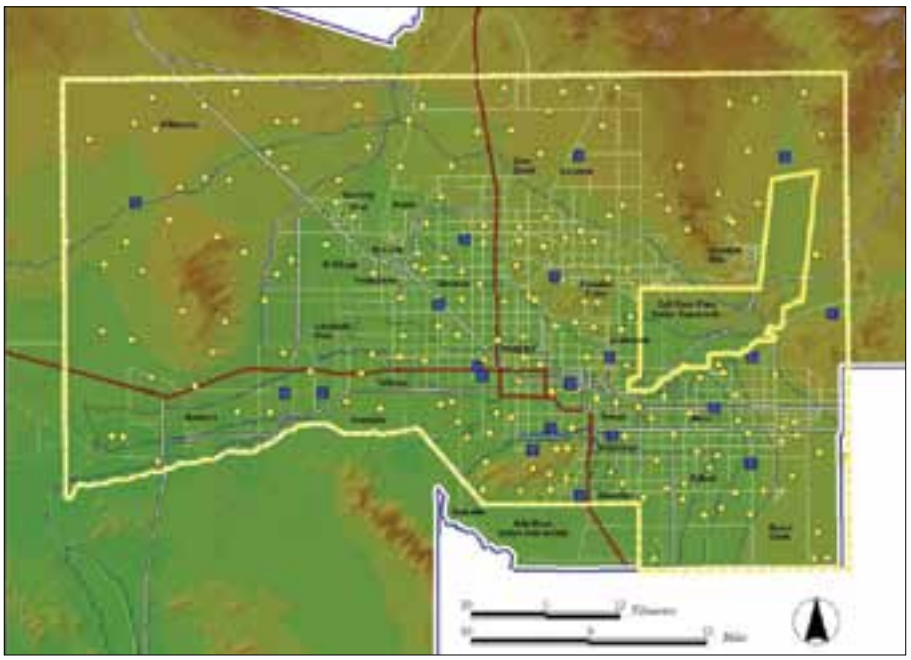
Urbanised areas cover about three percent of the earth's land surface, but account for about 80 percent of carbon emissions, 60 percent of residential water use, and close to 80 percent of the wood used for industrial purposes. Humans have not randomly selected places to build cities, and most are located where biodiversity and ecosystem services abound. This makes the "ecological footprint" of urban areas disproportionally large, often hundreds of times their physical sizes. Urbanisation is arguably the most drastic form of land transformation by humans, which profoundly affects the climate, environmental quality, biodiversity, and ecosystem services.

More than 50 percent of humanity lives in cities as of 2008, and this may reach 80 percent by 2050. Even after the world population stabilises around 2050, the proportion of urban residents will continue to grow. As former United Nations General Secretary Kofi Annan said, "The future of humanity lies in cities." This means that we must make our cities and urban regions sustainable. Unfortunately, numerous studies have shown that most, if not all, of our cities around the world have been on an unsustainable trajectory. To achieve urban sustainability, it is important to better understand the ecology of cities—in particular, how urbanisation affects biodiversity and ecosystem processes and services.

Although cities are places where human decisions and their socioeconomic consequences are realised, ecologists have focused primarily on "undisturbed" ecosystems, until recently. Cities were viewed, by many if not most ecologists, as "trashed" natural areas rather than unique ecosystems with their own characteristics. In the past few decades, an "urban ecology" movement has raced across the globe. Studying the pattern of urbanisation and its consequences for ecological and socio-economic processes have finally become mainstream in academia, emerging as a hot interdisciplinary field of study.

Phoenix, Arizona, has been at the forefront of this recent trend, and offers a unique opportunity for studying the ecology and sustainability of cities. Phoenix is in the middle of a desert; its population has been growing faster than almost anywhere else in the US; it consumes vastly more resources than are available locally. Some have argued that, if we can make it sustainable, we could make any city sustainable. In 1997, the U.S. National Science Foundation, for the first time, funded two "urban" Long-Term Ecological Research (LTER) projects, and Central Arizona-Phoenix became home to CAP-LTER. The study covers an area of 6,400 square kilometres, encompassing 24 municipalities of the Phoenix metropolitan region, as well as the surrounding agricultural fields and undeveloped Sonoran Desert. The central research question of CAP-LTER is: how do the patterns and processes of urbanisation 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? During the past 15 years, dozens of faculty members and more than 100 graduate students at Arizona State University have participated in CAP-LTER research activities, which have produced more than 350 publications.

In the rest of this article, we discuss the spatial pattern of urbanisation and its effects on biodiversity in the Phoenix metropolitan region, based on a number of studies associated with the CAP-LTER project.



3 The Study Area of the Central Arizona-Phoenix Long-Term Ecological Research Project

The Rise of Phoenix and Its Rapidly Changing Landscape

Situated in the northern part of the Sonoran desert, the Phoenix area is characterised by a hot and dry climate. The average summer temperature is 30.8 degrees Celsius, the average winter temperature is 11.3 degrees Celsius, and the annual precipitation is about 180 milimetres. Native vegetation is characterised by desert scrub communities, dominated by creosote bush (*Larreatridentata*), mesquite (*Prosopisglandulosa*), and several other shrub species, including the iconic trident-shaped saguaro cactus (*Carnegieagigantea*).

Phoenix is not the first community to inhabit the valley of the sun. The intersection of three rivers in this area was home to the Hohokam civilization from about 500–1400 AD. The Hohokam population reached about 100,000 at its peak, before it collapsed, probably because of a combination of extended droughts and major floods. The area remained deserted until the end of the American Civil War in 1865, when agricultural activities resumed. The Phoenix population remained smaller than 50,000 until after World War II. But since then, the area has rapidly developed into one of the major metropolitan regions in the US. Today, the greater Phoenix-metropolitan region has about four million people and accounts for more than 60 percent of the population of the state of Arizona. Now the sixth largest city in the country, Phoenix was one of the fastest growing cities in the US in the past several decades, prior to the crash of the housing market.

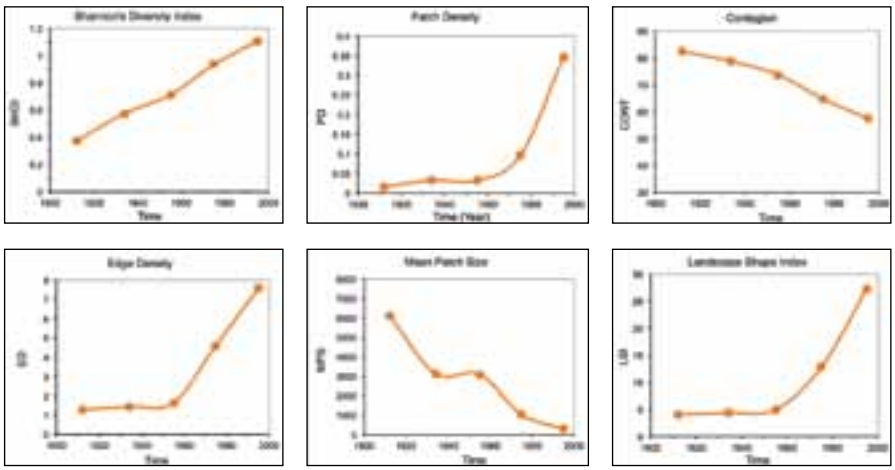
As urbanisation unfolds, the landscape of Phoenix has become increasingly diverse in composition, fragmented in structure, and complex in geometry. All these changes in landscape pattern have significant impacts on the biodiversity and ecosystem processes (and thus ecosystem services) in the metropolitan region. The effects of urbanisation on biodiversity are generally thought of, and often presented as, uniformly negative. While this is largely true at the global scale, the complexity of urban habitats and human actions can often result in positive effects on some types of biological diversity and ecosystem services. Here, we present a brief overview of biodiversity in Phoenix.

Biodiversity in Phoenix

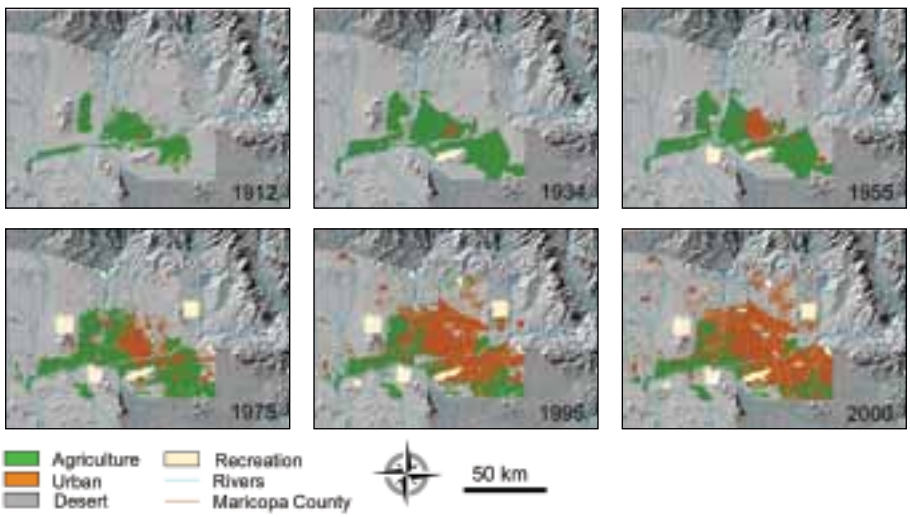
Plants

Despite being a desert city, vegetation plays an immense and complicated role in Phoenix's history, ecology, and economy, as well as individual backyards. Areas of "old town" central Phoenix can easily be confused with the suburban areas in New England. Irrigation ditches on either side of the road support majestic shade trees and dense hedgerows. Houses built prior to 1962 are eligible for plaques denoting their statuses in the historic register, and often display manicured lawns and carefully pruned rosebushes. The average residence in Phoenix uses three times as much water as a household in Boston, but pays about half as much per gallon.

Flood irrigation is a classic method of watering, whereby once a month, parks, graveyards, lawns, and sometimes entire neighborhoods are flooded with several inches of water that sink in over the course of a day or so. This reduces evaporation, but, with some of the lowest water prices in the entire country, more wasteful spray and mist irrigation is quite common. Increased evaporation associated with misting systems can lower nearby air temperatures by over 10 degrees Celsius and are also used by restaurants with outdoor seating from May through to October. A system of canals connecting three rivers, including the Colorado, allows for a sizeable agricultural industry, which remains the largest water user, accounting for between half to two-thirds of the yearly demand. Water-intensive crops, such as cotton, alfalfa, and citrus, now account for an even larger portion of the local economy following the crash of the housing



4 Quantifying the Changing Landscape of Phoenix



5 The Rapidly Changing Landscape of the Phoenix Metropolitan Region

3. (Image: CAP-LTER).

4. During urbanisation, the diversity of land-use types (Shannon's Diversity—SHDI) and the degree of fragmentation (Patch Density, Edge Density—PD, and ED) both have increased, while connectivity (Contagion—CONT) and the average size of patches (Mean Patch Size—MPS) have decreased. The geometric or shape complexity (Landscape Shape Index—LSI) has also increased exponentially (Image: CAP-LTER).

5. Urbanisation has taken place, increasingly, at the expense of agricultural land in recent decades. With continued water restrictions stalling agricultural development, housing construction accounts for a much greater proportion of economic growth, and the outlying desert is now being converted into urban areas (Image: CAP-LTER).

market that hit Phoenix particularly hard, though it did slow urban sprawl in the area. The city had previously been expanding into the surrounding desert at approximately one kilometre per year.

The majority of residences in Phoenix are part of private homeowners' associations, which control the landscaping used in communal areas and often restrict the types of vegetation that homeowners may plant on their property. One common stipulation prohibits brown grass. As traditional grass seed is very water-intensive and challenging to grow in the local climate, many people use Bermuda (or Devil's) grass, a hardier, drought-tolerant, and often invasive species, instead. Other solutions include using entirely artificial turf or painting dead grass green with a vegetable-based dye.

Concerns about water use have led to an increasing trend of "xeriscaping", which involves using native and exotic cacti, desert shrubs, and low water-use trees on a thin carpet of small stones and gravel. Some homeowners xeriscape their backyards while maintaining a "mesiscape" lawn in their front yard, or blend the two styles together, which is known as an "oasis". Like many cities, the intentional cultivation of exotic plant species results in Phoenix actually having higher overall plant diversity than the surrounding region. This is quite an accomplishment; while the Sonoran desert receives slightly less than the maximum annual precipitation that defines a desert (25 centimetres), it is home to over 2,000 plant species. The altered composition of plants in Phoenix has direct repercussions for urban herbivores, and indirect effects on predators whose prey depend on certain types of plants.

Not all of the people in Phoenix can afford to buy, plant, and maintain exotic vegetation. Plant diversity increases in areas with higher median household incomes, and this trend has an implication for environmental justice in the region. The built environment absorbs more thermal energy from the sun, and human activities produce waste heat. As a result Phoenix is three to four degrees Celsius warmer than the surrounding desert, known as the urban heat island effect. The cooling effect of shade trees and irrigation is therefore also correlated with affluence: a USD10,000 increase in median household income yields a 0.3-degree-Celsius decrease in surface temperature. The poorest neighbourhoods can be as much as 10 degrees Celsius warmer than the richest ones, and people with low incomes and no air conditioning have a much higher risk of heat stroke.

Reptiles and insects

In nearby Tucson, lizard diversity is actually highest in lightly developed suburban areas. A similar pattern has been found for birds and butterflies in other cities, presumably due to some combination of introduced species, more diverse habitats, and supplemental resources provided by humans in the form of food, water, and shelter. However, little is known about the few reptile species that survive in urban Phoenix. Approximately 14 native lizard species inhabit the surrounding desert, and 11 can be found in Phoenix's semi-natural, urban desert parks. Four of these species can be found in residential areas, but only the Ornate Tree Lizard has a nearly ubiquitous distribution throughout the city and the natural areas surrounding it. As is the case for many animals, species with very specific food and habitat requirements are less common in cities than those with more general preferences.

6. An oasis landscape. The foreground is xeriscaped, a mixture of native and exotic desert plants on gravel, which uses little water. The mesic landscape against the wall in the background is composed of palm trees, a broad-leaf tropical vine, and ferns. Though more water intensive, the evaporation and shade in this area results in noticeably lower temperatures (Photo: Jeffrey Ackley).

7. Horned lizards are adapted for camouflage, water conservation, and eat only certain native ant species. They are rapidly disappearing from urban areas in the southwest, where they no longer blend in, water is plentiful, and native ants are being displaced by invasive fire ants. Horned lizards also have to contend with novel predators, like housecats and humans (Photo: Jeffrey Ackley).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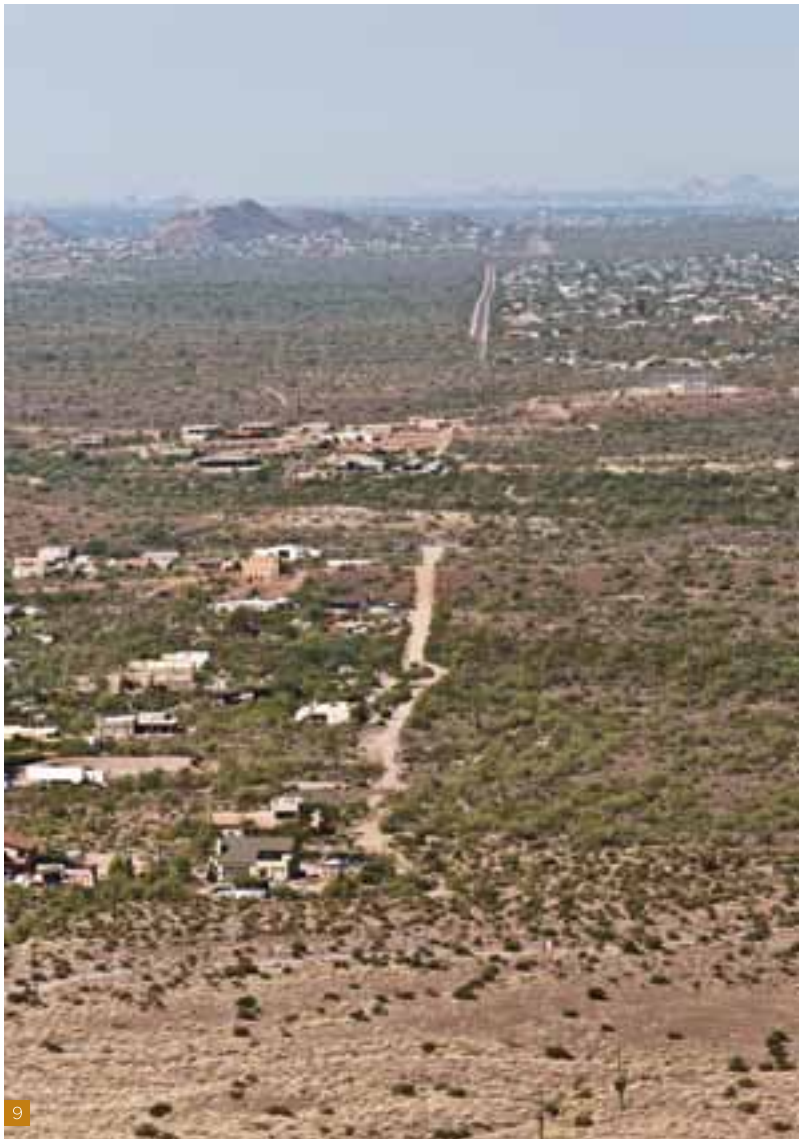
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8, 10. South Mountain is the largest municipal park in the continental US at approximately 6,500 hectares. Like almost all the desert parks in Phoenix, it escaped development by virtue of being too steep and rocky to build on. Almost all native mammals, birds, and reptiles can be found within its borders, except for a few species that require flat desert washes. As prime building sites, these habitats have disappeared within Phoenix. The tree pictured is a Palo Verde, or "green wood" in Spanish. It forgoes leaves to conserve water, and accomplishes photosynthesis by using the chlorophyll in the bark covering its trunk and branches, which gives it a green colour (Photos: Jeffrey Ackley).

9. Sprawl at Phoenix's urban fringe is often referred to as "leap-frog development". As land prices near existing residential areas are higher, developers would often "leap" past them, leaving a patchwork of desert remnants and housing blocks. The towers on the skyline constitute downtown Phoenix, the only area with a cluster of buildings higher than one or two storeys (Photo: Jeffrey Ackley).

Unlike birds, lizards and snakes take great risks when crossing roads, and undoubtedly urban habitat fragmentation is at least partly responsible for the reduction in their diversity. However, the urban heat island effect may also be playing a role. Lizards perform best only a few degrees below the maximum temperature they can tolerate. As cold-blooded animals, their body temperatures are tied to the environment, and an optimal habitat can become a lethal habitat after a small increase in temperature. Summer ground surface temperatures often exceed the relatively narrow range preferred by lizards (approximately 30 to 40 degrees Celsius) at midday, forcing them to retreat underground. The reduced time for foraging and mate finding associated with just two degrees Celsius of global warming was recently predicted to drive 40 percent of lizard populations extinct by 2080.

In Phoenix, lizards feed almost exclusively on insects, which, being ectotherms, are similarly restricted by the availability of their preferred temperatures in a habitat. Though insects generally have a wider tolerance range for temperature, their diversity is relatively similar inside the city and out. However, there are two distinctive groups: species commonly found in the desert and those commonly found in the city. The presence of buildings, lawns, exotic vegetation, and water from irrigation favours species different from those that are adapted to the native desert. Within Phoenix, the abundance of insects in mesic yards and agricultural areas is also much higher than in dry areas. With water resources no longer being the primary "bottom-up" control of insect population size, predation by urban bird species may be more important as a "top-down" control. Recurring surveys of insect diversity in remnant urban desert patches and xeric residential areas have shown a declining trend over recent decades, potentially due to increasing insecticide use and the isolation of these sites from potential colonisation by insect populations in the outlying desert.

Birds and mammals

In much the same way that most native reptiles are present within the larger urban desert parks, most native bird species are present within city limits. Like other urban areas, a mixture of exotic and native species can result in the highest bird diversity occurring near the city boundary, and low diversity at the urban core. While this local increase in diversity can be seen as good, the species that excel in urban areas often become extremely abundant, and in some cases become pests. Pigeons and house sparrows are quite common in urban areas, but as they are present in most cities, this results in a decline in diversity at regional and global scales. The presence of bird feeders has also led to a shift in species composition: birds in Phoenix are more likely to eat grain, while birds in the desert are more likely to eat insects. Many native species that do not thrive in Phoenix are adapted for efficient water use and drought tolerance, which is not very important in a city with golf courses, artificial lakes, bird baths, irrigation systems, and open water transport canals. Instead, the species that succeed here are those who are efficient foragers and tolerate human disturbances. Stress hormones are measurably higher in urban populations of birds than those from nearby rural areas.

In addition to introduced housecats, dogs, horses, and cattle, foxes can sometimes be found in residential areas, including those near Arizona State University in the heart of Tempe. Coyotes are still present in the larger urban parks, and desert Jackrabbits can be found in relatively small areas with native vegetation. Desert rodents are presented with a unique challenge in the city. To conserve water in the summer, they must burrow approximately a metre below the desert surface to where the temperature is below 36 degrees Celsius. With a four-degree-Celsius urban heat island effect and without supplemental water, they must now burrow two metres down to find equally cool temperatures.

Concluding Remarks

Cities have been the engines of economic development, cradles of innovation and knowledge production, and centres of sociocultural transformations. Cities also have a lower per capita cost of providing clean water, sanitation, electricity, waste collection, and telecommunications, while offering better access to education, jobs, health care, and social services, than rural areas. The potential to increase population density in existing cities without further urban sprawl is great if future urban development focuses on compactness and quality. All of these are important factors for the development of urban sustainability. As the human population continues to rise, the world will be increasingly urban and our well-being and prosperity will increasingly depend on the health of cities. Urban ecology is expected to play an instrumental role in improving existing cities and developing new ones that are more sustainable ecologically, economically, and socially. To realise this goal, urban ecology needs to develop relationships with design sciences.

Until now, positive instances of sustainable urban biodiversity and ecosystem services have been “happy accidents”—they occurred by chance. Deliberately constructing a novel habitat to be ecologically and socioeconomically beneficial is potentially contentious, but may be possible through the nascent relationship between urban ecology, sustainability science, landscape architecture, and urban planning—or “reconciliation ecology”, as Michael Rosenzweig called it.

Semi-natural urban spaces have been designed to provide specific services, and support certain forms of biodiversity, but why not others? Decision makers formed a particular vision of what these spaces would look like and function as, to the exclusion of many other design features and social goals. With the advent of citizen science, as well as participatory and trans-disciplinary research, the decision-making environment has now been both enriched and complicated by a diverse and growing cast of urban stakeholders who wield new sources of power, knowledge, and authority. Many of these are in conflict with historical values associated with areas like parks, and in some ways, represent a challenge to the traditional authority of urban management groups like municipal parks departments. We believe that improved scientific knowledge of and wider public participation in urban ecology are likely to play an increasing role in an ongoing, dynamic, and pluralistic *process* of urban design, management, and use. With the crash of the housing market, Phoenix’s primary economic engine slowed to a crawl. We hope this provides an opportunity for continually rethinking what we want Phoenix to look like, and how we want to sustain the people who live there amidst the Sonoran Desert.

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11, 12. The Desert Botanical Garden in Phoenix supports over 4,000 native and exotic plant species. This human control of vegetation in turn supports a variety of animal species, including high densities of birds and butterflies
(Photos: Jeffrey Ackley).