

How Do Humans Restructure the Biodiversity of the Sonoran Desert?

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Abstract—We studied patterns of biodiversity across the entire urban, suburban, agricultural, and surrounding Sonoran Desert landscape of central Arizona-Phoenix. A probability-based extensive integrated field inventory was used to survey perennial plants, pollen, birds, and sample soil chemistry, supplemented by monthly or quarterly monitoring of arthropod and bird communities at some sites. For taxa and ecosystem properties directly manipulated by people (e.g., perennial plant diversity, pollen) dominantly geomorphic controls in undeveloped desert were replaced by factors such as land use, agricultural legacy effects, income, and population density across the urban core. In contrast, native taxa indirectly affected by human activities (e.g., invertebrates and birds) showed modified diversity rather than widespread replacement, with reductions in ground arthropod, spider, and bee diversity, but increased bird diversity in some seasons.

Introduction

Although much ecological research has been carried out on the Sonoran Desert, the ways in which humans restructure ecosystem biodiversity in developed parts of the region has not been a focus of research. However, in 1997 the Central Arizona-Phoenix Long Term Ecological Research (CAP LTER) project was added to the network of sites funded by the National Science Foundation with the goal of understanding ecological patterns and processes of this rapidly expanding urban-desert region. In this paper, we outline the aims, methodology, and some of the main findings from our research on biodiversity to date, specifically on plants, pollen, arthropods, birds, and soil resources.

Aims and Methodology

The overall goal of CAP LTER is to understand how patterns and processes of urbanization alter ecological conditions in

central Arizona-Phoenix and how the ecological consequences of that change feed back to generate additional future changes. One of our specific aims is to analyze broad-scale patterns of biodiversity across the region and to document how various processes, particularly human drivers, rearrange and reshape those patterns. In this paper, we focus on the results from an extensive survey, supplemented by selected findings from more detailed studies.

Study Area and Sampling Design

Our study area covers 6,400 km², contains over 3 million people, and includes the rapidly expanding metropolitan Phoenix area as well as surrounding agricultural land and undeveloped Sonoran Desert. To obtain a spatially dispersed, unbiased sample of the ecological resources of this entire region, we used a dual-density, randomized, tessellation-stratified design (Stevens 1997; Peterson et al. 1999). This design consisted of a 4 km x 4 km grid from which one random sample

was taken in every square within the main Phoenix metro area and one sample in every third (random) square outside that area (figure 1). This resulted in approximately 100 samples inside and 100 samples outside the developed urban core, to take account of the greater landscape heterogeneity of the urban core (Luck and Wu 2002). From a total sample size of 206, access was denied for only 2 samples, giving a total of 204 sites surveyed.

Integrated Field Inventory and Statistical Analyses

A synoptic integrated field survey was carried out between late February and early May 2000 within a 30 m x 30 m plot at each sampling site. We mapped the main surface cover types (e.g., asphalt, soil, turf) and permanent built structures, collected soil cores (2.54 cm diameter, at 0 – 10 and 11 – 30 cm depth intervals) to determine major soil physical and chemical properties (Zhu et al., submitted; Hope et al., in preparation), and collected surface soil for pollen identification. At a randomly chosen sub-set of sites, we have conducted bird surveys quarterly since 2000 (N = 40, 15 minute, unlimited radius point counts, using both sight and sound, within 3 hours of sunrise). Land use was classified into one of five main categories: urban (n = 91), desert (n = 73), agriculture (n = 23), transportation (n = 6), and a “mixed” class (n = 11). We also obtained the following key geographic and socioeconomic variables: latitude, longitude, elevation, distance of each site from the urban center and from the nearest major freeway, the number of years each site had been in agricultural use, whether the site had ever been in agriculture, median family income, median age of housing stock, and human population density.

These were then used as independent variables to model spatial variations in plant diversity and soil nutrient concentrations, using both generalized linear modeling and Bayesian statistical techniques, after accounting for any spatial autocorrelation in the residuals, as described by Hope et al. (2003) and Oleson et al. (in preparation).

Other Studies

The above survey was supplemented by less extensive, more targeted work, which included ground arthropod pitfall trapping (McIntyre et al. 2001), a pollinator study (McIntyre and Hostetler 2001), and a study of birds and vegetation in municipal parks (Kinzig et al., submitted; Warren et al., submitted; Martin et al., in press).

Results

Plant Diversity

Overall, native plant diversity was only slightly lower across the developed urban core compared to the surrounding desert (table 1) and greatest at desert foothills sites around the urban fringe and edges of desert remnants within the city (figure 2). Plant community analyses of the data show three main native plant communities in the region—an *Enceli-Foothills Palo Verde* community, along with *Ambrosia*- and also *Larrea*-dominated communities (Gries et al., in preparation). However, while desert plots were dominated by native genera, urban plots had around half as many native compared to exotic genera (table 1), and at many developed sites native plant diversity is low or absent, replaced by numerous (total

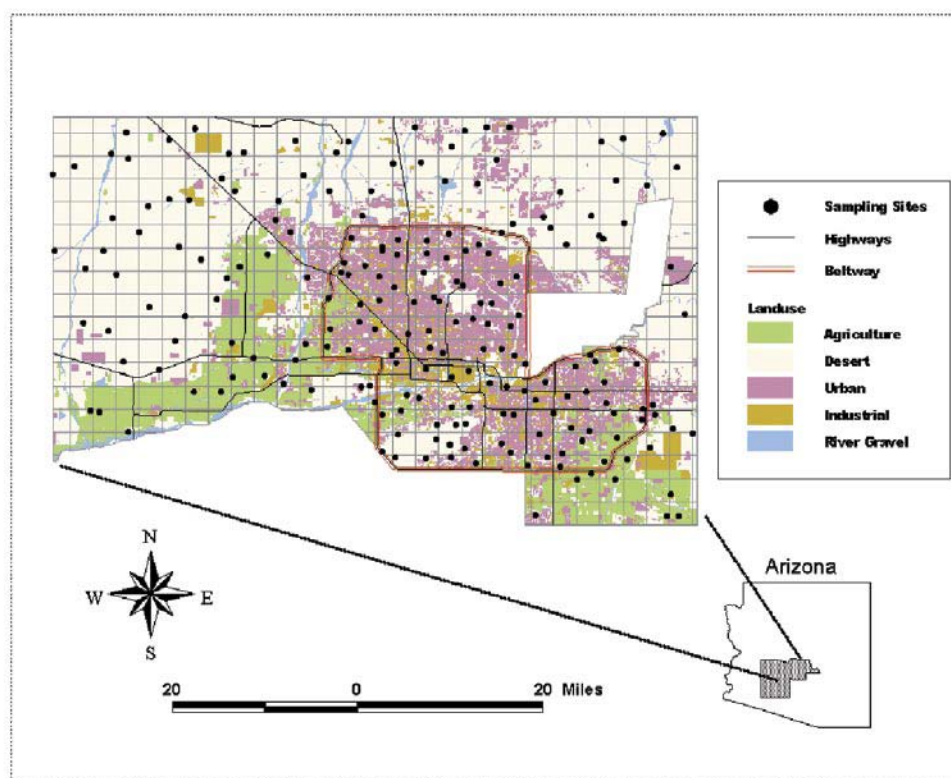


Figure 1—Map of the Central Arizona-Phoenix Long Term Ecological Research (CAP LTER) study site and extensive sampling scheme.

Table 1—Plant diversity (number of perennial genera per site) across CAP.

	Urban (n = 91)			Desert (n = 73)		
	All genera	Native	Exotic	All genera	Native	Exotic
Total (γ diversity)	156	50	117	63	55	6
Mean (α diversity)	8.0	4.2	8.0	8.4	9.0	1.5

of 117 non-natives) imported exotic genera comprising the human-created plant communities established by irrigation. This increased total plant richness (gamma diversity) across the region as a whole, with a total of 188 perennial plant genera recorded. Moreover, while the urban landscapes had a similar local diversity to the native desert vegetation they replaced (alpha = 8 genera per site), they had considerably higher compositional turnover, with a beta diversity of 7.5 in the desert, 19.5 in the city, and 26.7 for the region overall (Hope et al. 2003).

Perennial plant diversity was spatially autocorrelated among desert sites, reflecting the close correspondence of plant communities to topography, landform, water, and nutrient supply in the region (McAuliffe 1994; Whittaker and Niering 1975). There was no such relationship among urban sites, where perennial plant diversity reflected the influence of a combination of natural (e.g., elevation) and human factors such as income and agricultural legacy effects. Diversity at sites with per capita incomes over \$50,750 per year was on average twice that found

in less wealthy areas, and sites that were formerly farmed had 43% fewer woody plant genera than locations that had never been cultivated (Hope et al. 2003). Urban vegetation can be grouped into four broad communities—those with lawns, xeric landscapes containing *Prosopis*, “oasis” landscapes characterized by Queen Palms (*Syagrus*), and a fourth extremely diverse “catch-all” category that had no indicator species (Gries et al., in preparation).

Soil Nutrients

Comparison of the urban and undeveloped desert parts of the region suggest that soil resources are significantly affected by urbanization. Across the CAP region, soils at urban and agricultural versus undeveloped desert sites had higher moisture contents, more organic matter, and lower bulk density (Zhu et al., submitted). Soil nitrate ($\text{NO}_3\text{-N}$) concentrations were also higher at sites in the developed part of the ecosystem compared to desert sites, varying by up to

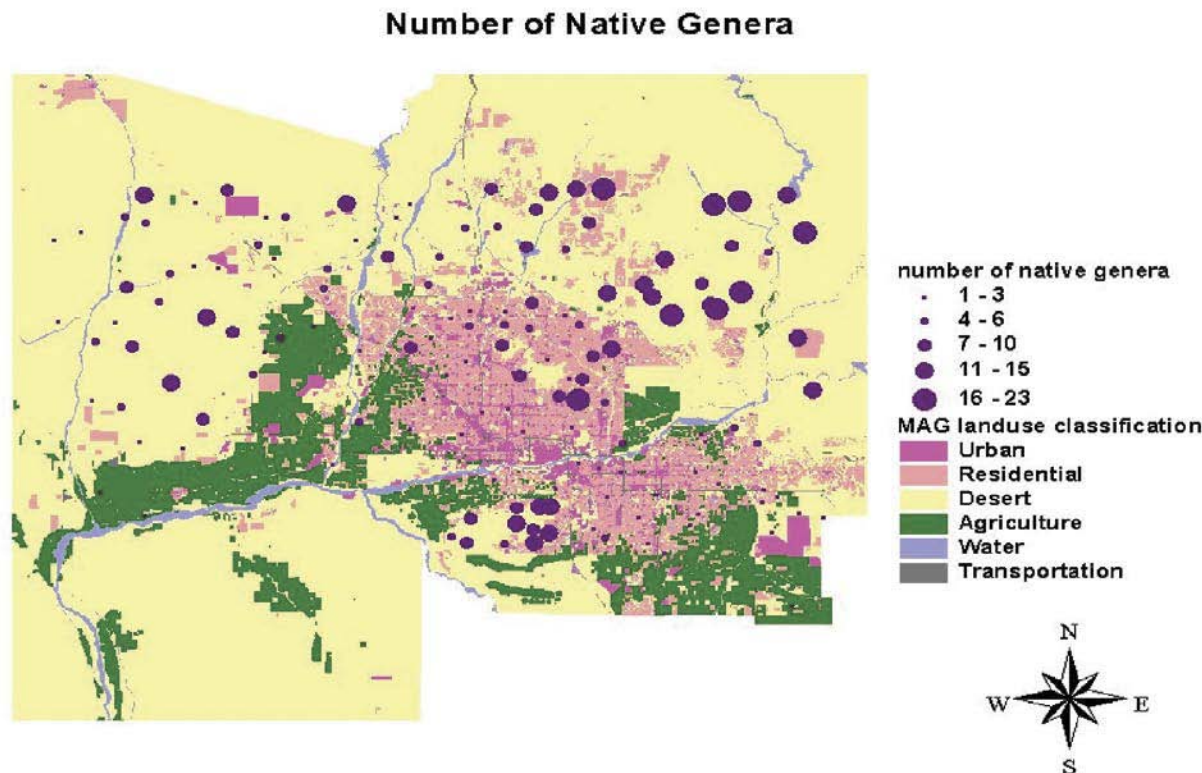


Figure 2—Map of native perennial woody plant diversity at each extensive survey site at CAP LTER. Plants were identified, to species where possible or to genus where the appearance of horticultural cultivars made accurate identification to the level of species difficult. Identification was standardized at the level of genus for subsequent statistical analysis, although in most study plots plant diversity on the genus level corresponds closely to diversity at the species level (Hope et al. 2003).

three orders of magnitude (Hope et al., submitted). These differences between developed versus desert sites persist even at sites located on same soil type and series, suggesting that pre-existing regional patterns of variation in soil properties cannot account for the observed patterns (Zhu et al., submitted). Statistical models show that dominantly geomorphic controls on spatial variation in soil nutrient concentrations in undeveloped Sonoran Desert are replaced by variables such as current and former land use, family income, population density, and housing age across urbanized parts of the region, as well as showing a clear legacy effect of higher soil nitrate concentrations at sites with current or former agricultural land use (Hope et al., submitted). These findings are similar to those for plant diversity (Hope et al. 2003). There tended not to be simple linear relationships between soil nutrient concentrations and independent variables for the urban sites. Rather, the *variation* in soil nutrient concentrations increases with changes in human population density, per capita income, elevation, and the like. This tendency toward higher variance in soil variables would seem to be a characteristic property of urban soils.

Pollen

We found widespread deposition of imported exotic pollen taxa across the region in addition to that from native desert species (Stuart et al., in revision). Relative abundances of native pollen inside the urban core have been reduced by increased abundance of pollen from exotic genera such as *Olea*, *Morus*, *Fraxinus*—the latter often creating local pollen deposition “hot spots” in areas where those plants are present in urban landscaping. Several desert taxa (e.g., *Ambrosia*, *Parkinsonia*, and xerophytes) feature strongly in the pollen record across the entire CAP region and show a strong correlation with extant vegetation cover on a site-by-site basis, clearly delineated by the major undeveloped Sonoran Desert areas (figure 3). Even *Pinus*, an imported genus with highly mobile pollen, shows a clear zonation across the central and southeastern part of the region, corresponding closely with the location of the oldest and most mature urban landscapes.

Arthropods

Ground dwelling arthropod species are abundant in urban settings and have been systematically monitored for the last five years at sites representing the four most common land use types across the metro area (residential, industrial, agricultural, and desert). While taxonomic richness was comparable among different land uses, community composition differed, certain taxa being associated with each land use type (McIntyre et al. 2001). Taxon-specific differences in community composition were related to habitat structure, the most important effects being due to presence of native vegetation, agricultural crops, or “exotic” habitats such as formal landscaping and buildings at residential and other developed plots (McIntyre et al. 2001). More detailed work on spider diversity has shown that

agricultural fields and mesic yards are characterized by higher spider abundance (particularly of wolf spiders *Lycosidae* and sheet-web weaver *Linyphiidae*) but lower diversity (Shochat et al. 2004). Meanwhile richness and abundance of bee species was generally lower in residential areas compared to desert, although residential yards that contained xeric landscaping have bee communities with higher diversity than mesic yards, suggesting that human choices in how they undertake urban development can be designed to maximize retention of native diversity (McIntyre and Hostetler 2001).

Bird Communities

Through systematic monitoring of birds over four seasons per year, we have recorded 166 species of birds in three of the four main land-use types: urban (77 spp.), desert (81 spp.), and agriculture (89 spp.). After controlling for sample sizes, bird diversity was highest in the desert, followed by urban and then agricultural land uses. Multivariate analysis found that bird species richness increased with median family income, plant volume, plant species diversity, and number of new houses (figure 4), although the relative importance of these factors varied seasonally (Katti et al., in preparation). These relationships are corroborated by results from a study of small urban parks, stratified by neighborhood socioeconomic status (Kinzig et al., submitted; Warren et al., submitted). While the urban avifauna is numerically dominated by a few exotic species (House sparrow *Passer domesticus*, Starlings *Sturnis vulgaris*, Rock Pigeon *Columbia livia*), it also supports significant populations of many native Sonoran species, including House Finch *Carpodacus mexicanus*, Abert’s Towhee *Pipilo aberti*, Cactus Wren *Campylorhynchus brunneicapillus*, and Curve-billed Thrasher *Toxostoma curvirostre*.

Discussion and Conclusions

We conclude that urbanization has resulted in a landscape in which biodiversity reflects social, economic and cultural influences in addition to those recognized by traditional ecological theory. There are two broad themes that emerge from our findings so far. First, the extent to which native diversity is affected by urbanization depends on the taxon in question. Native plant communities are still almost entirely replaced with exotics in urban landscapes across metro Phoenix, despite the increasing fashion for xeric residential landscaping over the last couple of decades. These urban plant communities have similar alpha diversity but much higher beta diversity than the native vegetation they replace. Taxa less directly affected by people (e.g., arthropods, birds) show less dramatic effects. Second, the broad gradients in a relatively small number of key drivers that govern biodiversity patterns in native Sonoran Desert (e.g., geomorphology, water and nutrient availability) are replaced by a much larger suite of interacting partially co-dependent variables in the city, including socioeconomic variables and land use legacies, which are often very site specific and result in a dramatic increase in spatial heterogeneity.

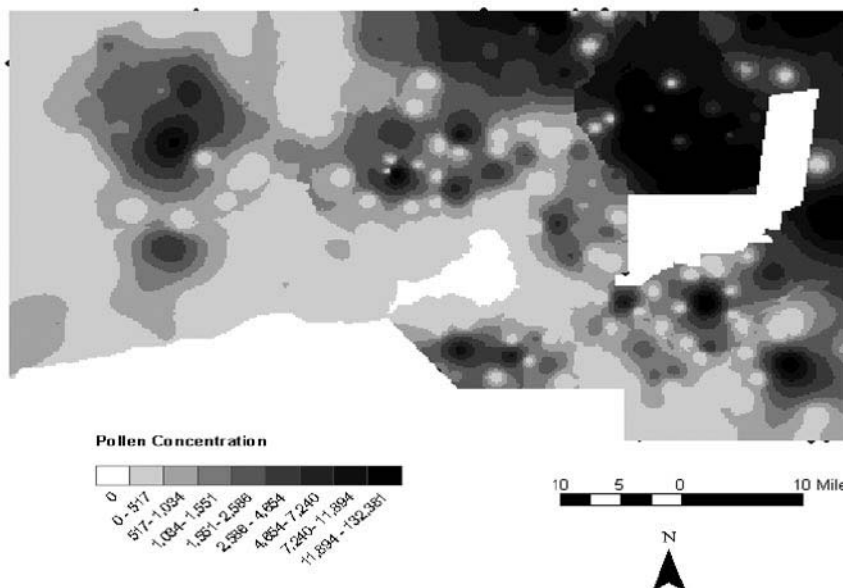


Figure 3—Contoured map of total xerophyte (all *Cactacea* and succulents) pollen concentrations across the CAP region.

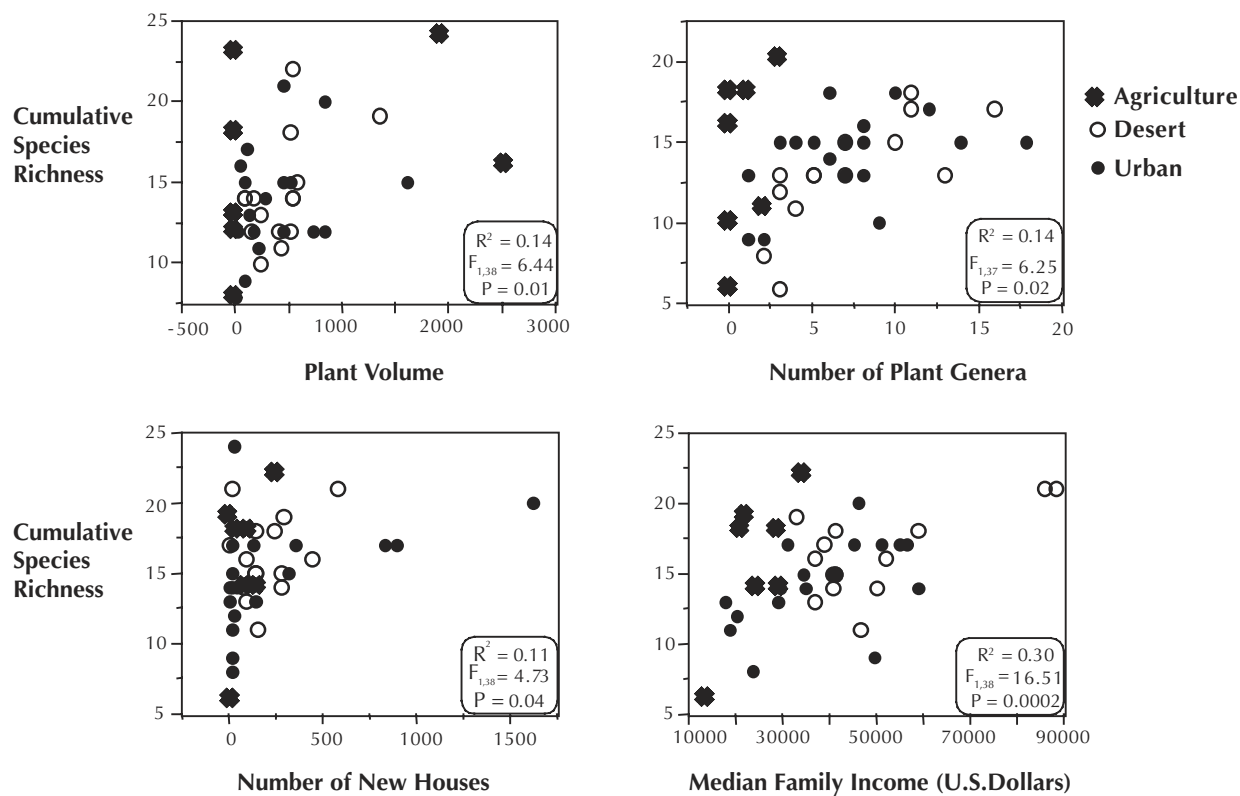


Figure 4—Determinants of bird species diversity in the CAP region. Graphs show significant bivariate relationships (with respective R^2 , F , and P values indicated in each case) between bird species richness and plant volume (upper left, spring), plant diversity (upper right, summer), number of new houses (lower left, summer), and median family income (lower right, summer). The strengths of these effects vary seasonally and from year to year, but these graphs represent the general patterns.

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