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Rich lizards: How affluence and land cover influence the diversity and abundance of desert reptiles persisting in an urban landscape

Jeffrey W. Ackley [a,*], Jianguo Wu [b,1], Michael J. Angilletta Jr. [a,2], Soe W. Myint [c,3], Brian Sullivan [d,4]

[a] School of Life Sciences, Arizona State University, PO Box 874501, Tempe, AZ 85287-4501, United States
[b] School of Life Sciences and School of Sustainability, Arizona State University, PO Box 874501, Tempe, AZ 85287-4501, United States
[c] School of Geographical Sciences and Urban Planning, Arizona State University, PO Box 875302-5302, Tempe, AZ, United States
[d] School of Mathematical and Natural Sciences, Arizona State University, PO Box 37100, Phoenix, AZ 85069-7100, United States

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ABSTRACT

Fourteen native lizard species inhabit the desert surrounding Phoenix, AZ, USA, but only two occur within heavily developed areas. This pattern is best explained by a combination of socioeconomic status, land-cover, and location. Lizard diversity is highest in affluent areas and lizard abundance is greatest near large patches of open desert. The percentage of building cover had a strong negative impact on both diversity and abundance. Despite Phoenix's intense urban heat island effect, which strongly constrains the potential activity and microhabitat use of lizards in summer, thermal patterns have not yet impacted their distribution and relative abundance at larger scales. As Phoenix emerges from an economic recession, efforts to restrict urban sprawl and encourage higher density development could lower water and energy use while benefiting lizards in undisturbed habitats. However, this would likely exacerbate the urban heat island effect, and pose a threat to native species within the urban landscape.

1. Introduction

Socioeconomic variables such as household income are correlated with ecosystem productivity (Buyantuyev and Wu, 2009) and urban biodiversity patterns of plants (Hope et al., 2003; Walker et al., 2009), birds (Kinzig et al., 2005; Lerman and Warren, 2011), and bats (Li and Wilkins, 2014). In some cases, these "top-down" controls have even more predictive power than the biophysical variables that regulate species distributions and relative abundance from the "bottom-up" (Luck et al., 2009). A ubiquitous "luxury effect" emerged from these studies, in which more affluent areas have higher biodiversity through ecosystem engineering, whereby homeowners introduce exotic plants and supplement natural sources of food and water for animals (Fuller et al., 2008). These changes in the structure and composition of habitats alter the diversity and abundance of arthropods (Bang and Faeth, 2011), which could also influence the habitat selection of highly mobile species such as bats.

Less mobile ground species, such as lizards, risk road mortality when moving in an urban environment and have less choice of which neighborhood they inhabit. However, their persistence in Phoenix, AZ, USA, may still be correlated with affluence because a $10,000 increase in median household income is associated with a 0.3 °C decrease in mean surface temperature (Jenerette et al., 2007). High summer temperatures can reduce the potential activity of lizards in Phoenix to one hour per day (Ackley et al., in press), and cooler temperatures in affluent areas could mitigate a heterogeneous urban heat island effect, which makes the city 3 °C warmer (on average) than the surrounding desert (Brazel et al., 2007). Since management efforts to reduce road mortality and heat stress would differ from efforts to enlarge and connect patches of suitable habitat, determining the relative importance of these variables at different scales will be crucial for managing native species in urban areas. Land-cover maps with a 1 m^2 resolution have recently become available for Phoenix (Li et al., 2014), enabling studies that integrate biophysical and socioeconomic variables with historical changes in the composition and configuration of landscapes. Many of these variables are correlated with each other,

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[*] Corresponding author. Tel.: +1 8604606778.

E-mail addresses: jwackley@asu.edu (J.W. Ackley), jingle.wu@asu.edu (J. Wu), michael.angilletta@asu.edu (M.J. Angilletta Jr.), soe.myint@asu.edu (S.W. Myint), BSULLIVAN@asu.edu (B. Sullivan).

[1] Tel.: +1 4809651063.

[2] Tel.: +1 4807276142.

[3] Tel.: +1 4809656514.

[4] Tel.: +1 6025436022.

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and may have complex relationships with lizard diversity (e.g., road density could impact dispersal, but may also influence lizards through increased surface temperatures). However, the proliferation of studies that only consider one or two threats to urban reptiles has resulted in uncertainty on how to best concentrate management efforts (Mitchell et al., 2008). Thus, the primary goal of our study is to determine which urban variables have the largest impacts on the diversity and abundance of native lizards.

2. Methods

2.1. Site selection

The Central Arizona-Phoenix Long-Term Ecological Research (CAP-LTER) project has established over 200 field sites within the city and surrounding desert (Grimm and Redman, 2004). We chose a subset of 28 sites along a gradient of urbanization, stratified by land-use type. Following a protocol similar to Germaine and Wakeling (2001), four sites were located in each of the following categories: desert, urban recreation/open space, agricultural, institutional/commercial, low density residential (>0 and $\leqslant$2 dwelling units per acre), medium density residential (>2 and $\leqslant$5 dwelling units per acre) and high density residential (>5 dwelling units per acre). These land-use categories are roughly equal in relative abundance within Phoenix. Selected plots could not be alongside a $\geqslant$4 lane road, within 0.5 km of an interstate highway, within heavy industrial/commercial areas without open space/landscaping, within 3 km of a previously selected plot, above 600 m elevation, or inaccessible to private citizens by car or foot.

2.2. Response variables

Lizard diversity (number of species per site) and abundance data (lizards per site) were collected by the same person (JWA), using 20 min visual transect surveys at each site. This person scanned the area within 10 m on each side of a 200 m transect for lizards. Time spent identifying species with binoculars was not counted. The orientation and shape of transects were often dictated by roads, in which case it was walked once on each side. As this approach resulted in non-linear transects at many urban sites and some desert sites, the circular buffers mentioned below were drawn as close as possible to the center of the area surveyed. Each site was surveyed twice during fall 2012 (September–October), and four times during spring 2013 (March–May). Surveys were varied to accommodate the range of conditions in which different species were active (25–39 °C air temperature and 08:00–18:00 h on days with low wind and cloud cover). Unidentified lizards were only included in abundance estimates. A site at which only one unidentified lizard was observed was treated as having one species present.

2.3. Explanatory variables

We collected a preliminary data set comprising nearly 50 variables from three functional groups. (1) Site-scale characteristics included measures of habitat area, isolation, land-use history, temperature, traffic, and affluence. (2) Percent abundance of land-cover types within circular buffers of 200-m, 500-m, and 2-km diameter. (3) Landscape-scale metrics of all land-cover types (patch diversity, density, shape, size, spatial configuration, etc.) measured within the same buffers. As expected, Spearman's Rank correlation and a test of variance inflation factors (VIFs) (O'brien, 2007) identified many of these variables as highly correlated; therefore, we began a process of reducing this collinearity to acceptable levels. Data reduction approaches such as principal component analysis (PCA) were not applicable as the preliminary set of explanatory variables was larger than the number of sites we surveyed for lizards.

Extremely high correlations were found between different buffer sizes of the same land-cover types and landscape metrics. Redefining the 500 m and 200 m extents as the difference between their values and the extent they were nested within ($500\ \mathrm{m}_{\mathrm{new}} = 500$ m–2 km, $200\ \mathrm{m}_{\mathrm{new}} = 200$ m–500 m) (Zuur et al., 2009) did not reduce their correlations to acceptable levels, so we eliminated the 500-m and 2-km variables because the 200-m extent directly matched the area we surveyed for lizards. The remaining 25 variables were further reduced to 14 by eliminating one of each pair that produced a rank correlation over 0.7. We retained variables according to their management potential, source quality, distinctiveness within our dataset, and if it had been identified as having a significant effect on lizards in previous studies. The final set of 14 variables had variance inflation factors approaching 30, but those in the most likely statistical models had variance inflation factors and rank correlations well below acceptable limits (less than 5 and 0.5, respectively) (Graham, 2003; O'brien, 2007).

We calculated the final set of site variables (see Fig. 2 below) as follows. Straight-line distance to a large desert patch (>5 km^2) was measured in ArcGIS. Median household income was determined from data collected during the 2010 US census (block group data from Maricopa County). Years since a >25% land-cover change was calculated from historical aerial imagery, which are available for Phoenix in ~15 year intervals from 1937 to 1990, and ~2 year intervals from 1990 to 2013. The spatial standard deviation of surface temperatures within circular buffers 200 m in diameter was calculated using the Geospatial Modelling Environment and ArcGIS from one of the final images taken by NASA's Landsat 5 Thematic Mapper (Landsat TM) satellite during a day in September 2011 before it was decommissioned. While this was a year before we began collecting lizard data, development (and changes in relative surface temperature differences between sites) had largely stalled following the economic recession. Previous surface temperature images taken in summers of 2010 and 2011 had a correlation of 0.8, despite differences in average temperature between years. We used the standard deviation instead of mean or maximum temperatures for three reasons. First, areas with slightly lower mean temperatures have much greater temperature variance. Second, thermal variation actually impacts potential activity of lizards in Phoenix much more strongly than mean temperatures does (Ackley et al., in press). Third, if future warming in Phoenix imperils the potential for lizards to survive, thermal variation will likely dictate local extinctions rather than maximum temperatures (Ackley et al., in press). Traffic density was calculated within a circular buffer 2 km in diameter, using the Geospatial Modelling Environment and ArcGIS. We used a larger buffer because the data were much coarser in resolution than those for land-cover and temperature. Traffic data were based on a validated model obtained from the Maricopa Association of Government's Transportation Division. Unlike observed traffic counts, modeled traffic data are available for all major road segments within the Phoenix Metropolitan Area. The most recent traffic counts were from 2008. As with temperatures, while average traffic density might have changed since then, relative differences between sites likely remained similar.

We calculated percent abundance of land-cover types using the Geospatial Modelling Environment and ArcGIS from a map with a resolution of 1 m^2 (Li et al., 2014). The classification included trees, grass, shrubs, pavement (roads, sidewalks, and parking lots), buildings, agriculture, and bare soil (including rock). Permanent water was not included in our analysis as it almost never occurred within 200 m of our sites; swimming pools were also removed due to their low relative abundance and a high correlation with grass