# Urban Naturalist

No. 2 2014

## Historic and Current Composition of Lizard Communities in Urban Preserves of Central Arizona, USA

Brian K. Sullivan, David Vardukyan, and Keith O. Sullivan

# The *Urban Naturalist* . . .

- ♦ A peer-reviewed and edited interdisciplinary natural history science journal with a global focus on urban areas ( ISSN 2328-8965 [online]).
- ♦ Featuring research articles, notes, and research summaries on terrestrial, fresh-water, and marine organisms, and their habitats. The journal's versatility also extends to publishing symposium proceedings or other collections of related papers as special issues.
- ♦ Focusing on field ecology, biology, behavior, biogeography, taxonomy, evolution, anatomy, physiology, geology, and related fields. Manuscripts on genetics, molecular biology, anthropology, etc., are welcome, especially if they provide natural history insights that are of interest to field scientists.
- ♦ Offers authors the option of publishing large maps, data tables, audio and video clips, and even powerpoint presentations as online supplemental files.
- ♦ Proposals for Special Issues are welcome.
- ♦ Arrangements for indexing through a wide range of services, including Web of Knowledge (includes Web of Science, Current Contents Connect, Biological Abstracts, BIOSIS Citation Index, BIOSIS Previews, CAB Abstracts), PROQUEST, SCOPUS, BIOBASE, EMBiology, Current Awareness in Biological Sciences (CABS), EBSCOHost, VINITI (All-Russian Institute of Scientific and Technical Information), FFAB (Fish, Fisheries, and Aquatic Biodiversity Worldwide), WOW (Waters and Oceans Worldwide), and Zoological Record, are being pursued.
- ♦ The journal staff is pleased to discuss ideas for manuscripts and to assist during all stages of manuscript preparation. The journal has a mandatory page charge to help defray a portion of the costs of publishing the manuscript. Instructions for Authors are available online on the journal's website (www.eaglehill.us/urna).
- ♦ Co-published with the *Northeastern Naturalist* (Print ISSN # 1092-6194, Online ISSN # 1938-5307), the *Southeastern Naturalist* (Print ISSN # 1528-7092, Online ISSN # 1938-5412), and *Caribbean Naturalist* (ISSN # 2326-7119 [online]). Together these journals provide an integrated publishing and research resource for all of eastern mainland North America and the offshore waters and islands from Canada south to the Caribbean region, as well as urban areas worldwide.
- ♦ Available online in full-text version on the journal's website (www.eaglehill.us/urna). Arrangements for inclusion in the BioOne database (www.bioone.org, a collaborative effort of Allen Press, AIBS, et al.), EBSCOhost product line, and the Proquest Information and Learning databases (www.il.proquest.com) are being pursued.
- ♦ May be ordered through any major subscription service.

**Cover Photographs:** View from the South Mountain Preserve looking north across Central Phoenix, AZ, USA (photograph © Brian Sullivan). Inset photos from left to right: The Regal Horned Lizard (*Phrynosoma solare*), the only lizard known to have been lost from an interior mountain preserve in the Phoenix area over the past 20 years (photograph © Brian Sullivan); a male "South Mountain" Chuckwalla (*Sauromalus ater*)—note the orange tail, which distinguishes it from Chuckwallas found elsewhere (photograph © David Vardukyan); and a male Desrt Spiny Lizard (*Sceloporus magister*), one of the 5 most abundant lizard species in the Phoenix metropolitan region (photograph © Daniel Dawson).

URBAN NATURALIST

## Board of Editors

Myla Aronson, Rutgers University, New Brunswick, NJ, USA
Kerry Barringer, Brooklyn Botanical Garden, New York, NY, USA (retired)
Andrea Larissa Boesing, Universidade Estadual de Londrina, Parana, Brazil
Sabina Caula, Universidad de Carabobo, Naguanagua, Venezuela
Sylvio Codella, Kean University, Union New Jersey, USA
Julie Craves, University of Michigan-Dearborn, Dearborn, MI, USA
Rebecca W. Dolan, Friesner Herbarium and the Center for Urban Ecology, Butler University, Indianapolis, IN ... **Managing Editor**
Ana Faggi, Universidad de Flores/CONICET, Buenos Aires, Argentina
Keith Goldfarb, Eagle Hill Institute, Steuben, ME, USA ... **Editor-in-Chief**
Chad Johnson, Arizona State University, Glendale, AZ, USA
Madhusudan Katti, California State University- Fresno, CA, USA
Erik Kiviat, Hudsonia, Bard College, Annandale-on-Hudson, NY, USA
Sonja Knapp, Helmholtz Centre for Environmental Research–UFZ, Halle (Saale), Germany
David Krauss, City University of New York, New York, NY, USA
Mark Laska, Great Ecology, consulting, La Jolla, CA, USA
Susannah Lerman, University of Massachusetts, Amherst, MA, USA
Kristi MacDonald, Hudsonia, Bard College, Annandale-on-Hudson, NY, USA
Ian MacGregor-Fors, Insituto de Ecología Mexico, Veracruz, Mexico
Brooke Maslo, Rutgers University, New Brunswick, NJ, USA
Mark McDonnell, Royal Botanic Gardens Victoria and University of Melbourne, Melbourne, Australia
Mike McKinney, University of Tennessee, Knoxville, TN, USA
Mitchell Pavao-Zuckerman, University of Arizona, Tucson, Arizona, USA
Joseph Rachlin, Lehman College, City University of New York, New York, NY, USA
Travis Ryan, Center for Urban Ecology, Butler University, Indianapolis, IN, USA
Michael Strohbach, Humboldt Universität zu Berlin, Berlin, Germany
Katalin Szlavecz, Johns Hopkins University, Baltimore, MD, USA
Andrea Townsend, University of California-Davis, Davis, CA, USA
Paige Warren, University of Massachusetts, Amherst, MA, USA
Jill Weber, Eagle Hill Institute, Steuben, ME, USA ... **Production Editor**
Peter Werner, Institut Wohnen und Umwelt, Darmstadt, Germany
Iriana Zuria, Universidad Autónoma del Estado de Hidalgo, Hidalgo, Mexico

The ***Urban Naturalist*** (ISSN # 2328-8965) is published by the Eagle Hill Institute, PO Box 9, 59 Eagle Hill Road, Steuben, ME 04680-0009. Phone 207-546-2821, FAX 207-546-3042. E-mail: office@eaglehill.us. Webpage: www.eaglehill.us/urna. Copyright © 2014, all rights reserved. Periodical postage paid in Steuben, ME and additional mailing offices. **Special issue proposals are welcome**. On-line secure subscription ordering: rate per year - $20 regular, $15 students, $80 organizations. **Authors**: submission guidelines are available at www.eaglehill.us/una. **Co-published journals:** The *Northeastern Naturalist* (ISSN 1092-6194 [print], ISSN 1938-5307 [online]), the *Southeastern Naturalist* (ISSN 1528-7092 [print], ISSN 1938-5412 [online]), and the *Caribbean Naturalist* (ISSN 2326-7119), journals with separate Boards of Editors. The Eagle Hill Institute is a tax exempt 501(c)(3) nonprofit corporation of the State of Maine (Federal ID # 010379899).

# Historic and Current Composition of Lizard Communities in Urban Preserves of Central Arizona, USA

Brian K. Sullivan[1,*], David Vardukyan[2], and Keith O. Sullivan[3]

**Abstract -** Urbanization is rapidly enveloping isolated remnants of Sonoran Desert habitat in southern Arizona. Understanding the means by which herpetofaunal elements can persist in these habitats in the face of multiple impacts is vital to conservation efforts to retain intact biotic communities, especially those with a high diversity of reptile species. We surveyed twelve preserves in the Phoenix Metropolitan region, five of which had been surveyed decades earlier, and obtained estimates of the diversity (species richness) and relative abundance of lizards. In comparison to surveys of the same preserves 20 to 40 years prior, one lizard species is absent from one large preserve where it was once present, but communities are otherwise largely similar in diversity and abundance over the past few decades. Larger preserves have higher diversity but not higher abundance of lizards. The range in diversity indices (i.e., species richness and evenness) across preserves we documented encompasses the range in diversity indices derived from other studies of urban lizard communities in the Southwest. Individual variation in distribution and abundance of component species must be investigated to adequately assess declines at the community level. We lack historically detailed data on distribution of many lizards and snakes, preventing an accurate analysis of species loss over the past 50 years.

## Introduction

The Sonoran Desert of the southwestern United States is under increasing pressure from expanding metropolitan areas, most notably Phoenix—an urban landscape stretching across more than 20,000 km$^2$ of arid lands in central Arizona (Kane et al. 2014). Impacts associated with this seemingly ever-expanding metropolitan area have been varied, but one outcome has been the isolation of a variety of preserves, patches of remnant habitat enveloped by this urban sprawl (Esbah et al. 2009, Sullivan et al. 2014). These preserves literally represent islands of desert habitat in a sea of urbanization, varying in both age since separation from any surrounding natural habitat and in size, as well as a host of other factors. These sites contrast with the adjacent areas that have been directly converted to some form of anthropogenic habitat, primarily housing or agricultural lands. Some areas were converted to agricultural lands over 100 years prior and were only recently transitioned to high-density housing. Others, especially on the edge, were more recently turned from desert directly to high-density housing without any patches of remnant habitat. Last, some regions were converted to complex patches of low-density hous-

[1]PO Box 37100, School of Mathematical and Natural Sciences, Arizona State University, AZ 85069-7100, USA. [2]School of Life Sciences, Arizona State University, PO Box 874501, Tempe, AZ 85287-4501, USA. [3]Contracts Branch, Arizona Game and Fish Department, Phoenix, AZ 85086, USA. [*]Corresponding author - bsullivan@asu.edu.

Manuscript Editor: David Krauss

ing and remnant habitat patches, generally in affluent neighborhoods (see reviews in Ackley et al., in press; Esbah et al. 2009; Litteral and Wu 2012).

Knowledge of relationships between key environmental variables and diversity and abundance of vertebrates, especially in natural areas isolated within urban landscapes, is increasingly important to conservation (reviewed in Davis et al. 2013, MacNally and Brown 2001, Sullivan and Williams 2010). Trubl et al. (2011) argued that understanding ecological factors associated with decline of many native organisms, often in stark contrast to expansion of some native and especially non-native forms, is vital to advancing our management of remnant preserves within urban areas, and to the mitigation of anthropogenic impacts in outlying areas while native forms are still present. Our understanding of how reptiles respond to anthropogenic impacts on habitat structure within remnant communities is increasing rapidly, at both the community level (e.g., Garden et al. 2007, Koenig et al. 2001) and species level (e.g., Barrows et al. 2008, Fisher et al. 2002, French et al. 2008, Sullivan et al. 2004). Nonetheless, we still lack basic historical information, such as presence and absence of various species, for the vast majority of reptiles impacted by urbanization.

There is growing evidence that identification of critical ecological factors is vital to conservation of squamate reptiles (Buckley and Jetz 2010, Fischer et al. 2005). For example, Sullivan and Williams (2010) documented that plant diversity accounted for 75% of the variation in abundance of the lizard *Sauromalus ater* (Dumeril) (Common Chuckwalla) across a series of Sonoran Desert preserves. Similarly, Sullivan et al. (2014) documented the presence of *Phrynosoma solare* Gray (Regal Horned Lizard) in 50% of the Phoenix area preserves they surveyed in spite of the fact that these lizards have been collected for the pet-trade for well over 100 years and the fact that close relatives have suffered significant declines in some areas (Fisher et al. 2002, Jennings 1987). Horned lizards are dietary specialists feeding almost exclusively on seed-harvester ants, depending on the species (reviewed in Sherbrooke 1981, 2003), and it appears these lizards may persist if their primary prey persist (Sullivan et al. 2014). Such investigations indicate that conservation of some reptiles can be enhanced by consideration of a relatively small number of ecological attributes across preserves (Kitchner et al. 1980, Martin and Lopez 2002, Santos et al. 2008, Sarre et al. 1995).

## Study sites and hypothesis under test

Sullivan and Flowers (1998) hypothesized that Phoenix Mountain Preserves, established over the past six decades, provide a non-random array of habitats that favor herpetofauna species which prefer rocky microhabitats. These preserves are primarily upland slope habitat (steep, rocky formations) with relatively few washes or expansive flats (sandy soils with little elevational gradient; Fig. 1). They documented that five interior preserves, isolated islands of rocky habitat, continue to support populations of saxicolous squamates (e.g., Common Chuckwalla) but appear to lack those taxa typically restricted to alluvial soil flats such as *Phyrnosoma* spp. (horned lizards), *Dipsosaurus dorsalis* (Baird and Girard) (Desert Iguana), and *Gambelia wislizenii* Baird and Girard (Long-nosed Leopard Lizard). They concluded that the lack of habitat heterogeneity present in the primarily upland slopes of the preserves in large measure accounted for the lack of lizard diversity they observed—as few as three species in some preserves and only nine in the largest preserve—relative to approximately a dozen species known from just outside the Phoenix Metropolitan region (Table 1, Appendix 1). Sullivan and Flowers (1998) documented that one preserve, the largest interior preserve in the metropolitan area and containing ~2 km$^2$ of flats, still retained horned lizards in the 1990s (1995–1998).

In a continuing effort to more adequately evaluate the factors influencing the efficacy of the current preserve system in providing habitat for historic herpetofauna

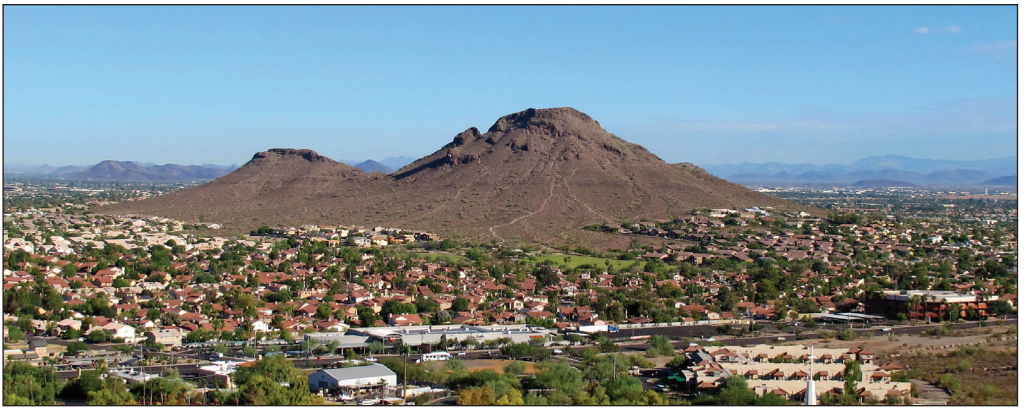

Figure 1. Lookout Mountain Preserve, one of the smallest preserves; note the absence of Creosote-Bursage flats and xeric washes.

Table 1. Diversity (number of species detected) and abundance (average number of lizards observed each 60-min survey) for all sites surveyed. Diversity did not vary across time periods (Wilcoxon Matched-pairs, signed ranks: Z = 1.73, $P = 0.083$, $n = 8$ sites), nor did abundance (Wilcoxon Matched-pairs, signed ranks: Z = 0.75, $P = 0.462$, $n = 6$ sites).

| | Diversity | | Abundance | |
|---|---|---|---|---|
| Site | 1990s | 2010s | 1990s | 2010s |
| Adobe Dam (AD) | 7 | 6 | - | 17.8 |
| Cave Buttes (CB) | 7 | 6 | - | 22.2 |
| Hedgpeth (HH) | 3 | 3 | 4.5 | 5.8 |
| Lookout (LO) | 3 | 3 | 10.1 | 17.6 |
| North (NM) | 4 | 4 | 8.4 | 11.1 |
| Piestewa Peak (PP) | 6 | 5 | 12.0 | 10.0 |
| Shadow (ShM) | 4 | 4 | 12.1 | 8.2 |
| South (SM) | 9 | 9 | 18.3 | 13.4 |
| Papago Park (PPk) | - | 3 | - | - |
| Deem Hills (DH) | - | 6 | - | 25.5 |
| Rose Garden Lane (RGl)- | 6 | - | 36.2 | |
| New River (NR) | - | 6 | - | - |
| Estrella Park | - | 11 | - | - |
| Pinnacle Peak Park | - | 10 | - | - |
| San Tan Park | - | 10 | - | - |
| White Tank Park | - | 13 | - | - |

in the Phoenix region, we selected a larger array of sites than those originally sampled by Sullivan and Flowers (1998), and added two sites that represent flood plain recreational areas with abundant alluvial soil patches rather than exclusively upland, mountain preserves. Adobe Dam (AD) and Cave Buttes (CB) are large sites on the northern metropolitan edge that comprise all major local habitat types, including large areas of *Larrea tridentata* (D.C.) Coville (Creosote Bush) - *Ambrosia deltoidea* (Torr.) Payne (Triangle Bursage) flats dominated by fine textured alluvial soils (see Jones et al. [2011] and Sullivan et al. [2014] for discussions of this habitat in the Sonoran Desert biotic community). AD and CB were surveyed intensively from 1990 to 1995, primarily with respect to the amphibian communities, but incidental observations were gathered on reptiles encountered while conducting amphibian surveys (Sullivan and Fernandez 1999). We returned to these sites in 2010 and conducted surveys over the next 48 months to document the reptile community; we also revisited the interior sites surveyed by Sullivan and Flowers (1998), and added additional sites that had been established as preserves over the last decade to bring the total surveyed to 12 preserves of varying sizes and habitat constitution (Table 1). Herein we present the results of the 2010–2014 surveys from these 12 metropolitan preserves, and compare those to data from Sullivan and Flowers (1998) and Parker (1967). We specifically evaluate the changes in diversity (= species richness) and abundance of lizards from the preserves surveyed by Sullivan and Flowers (1998) in the mid-1990s and the one preserve (South Mountain) surveyed intensively by Parker (1967) in the mid-1960s.

## Methods

A total of 12 sites in the Phoenix Metropolitan area were surveyed for lizards: Adobe Dam (AD), Cave Buttes Dam (CB), Deem Hills (DH), Hedgpeth Hills (HH), Lookout Mountain (LO), New River Dam (NR), North Mountain (NM), Papago Park (PPk), Piestewa Peak (PP), Rose Garden Lane (RGL), Shadow Mountain (ShM), and South Mountain (SM) (Fig. 2). Additionally, four sites on the edge of the Phoenix metropolitan region—Estrella, San Tan, and White Tank Mountain regional parks, and Pinnacle Peak Park—were selected for “historical baseline” reference comparisons of lizard diversity in similar Sonoran Desert habitats independent of the surveys presented herein. These four sites were used because complete inventories of the squamate communities were available as a consequence of detailed studies conducted in the vicinity during the 1990s and early 2000s (inventoried over the course of studies on a variety of squamate taxa; see citations in Sullivan and Kwiatkowski 2007). We used the four outlying sites and a fifth non-preserve metropolitan area site with documented shifts in lizard diversity and abundance over the years, the Desert Botanical Garden adjacent to one of the interior preserves (PPk), to compare historic diversity of lizard communities with extant preserves. Because our intention was to specifically test the hypothesis of Sullivan and Flowers (1998) that creosote-bursage flats are critical to site occupancy by various lizards, we focused on those habitats within preserves (as opposed to washes or rocky slopes).

Two approaches were used to survey for lizards. To obtain standardized estimates of relative abundance in the more recent surveys (2010–2014), three to five visual encounter surveys (VES), each for 60 min, were conducted in each of the five primary sites (LO, NM, PP, ShM, SM) surveyed by Sullivan and Flowers (1998), and a sixth site, HH, surveyed as part of a Common Chuckwalla survey (Sullivan and Sullivan 2008). Data from three 60-minute surveys conducted 1994–1996 were available for six sites (HH, LO, NM, PP, ShM, SM; Sullivan and Flowers 1998), but only diversity

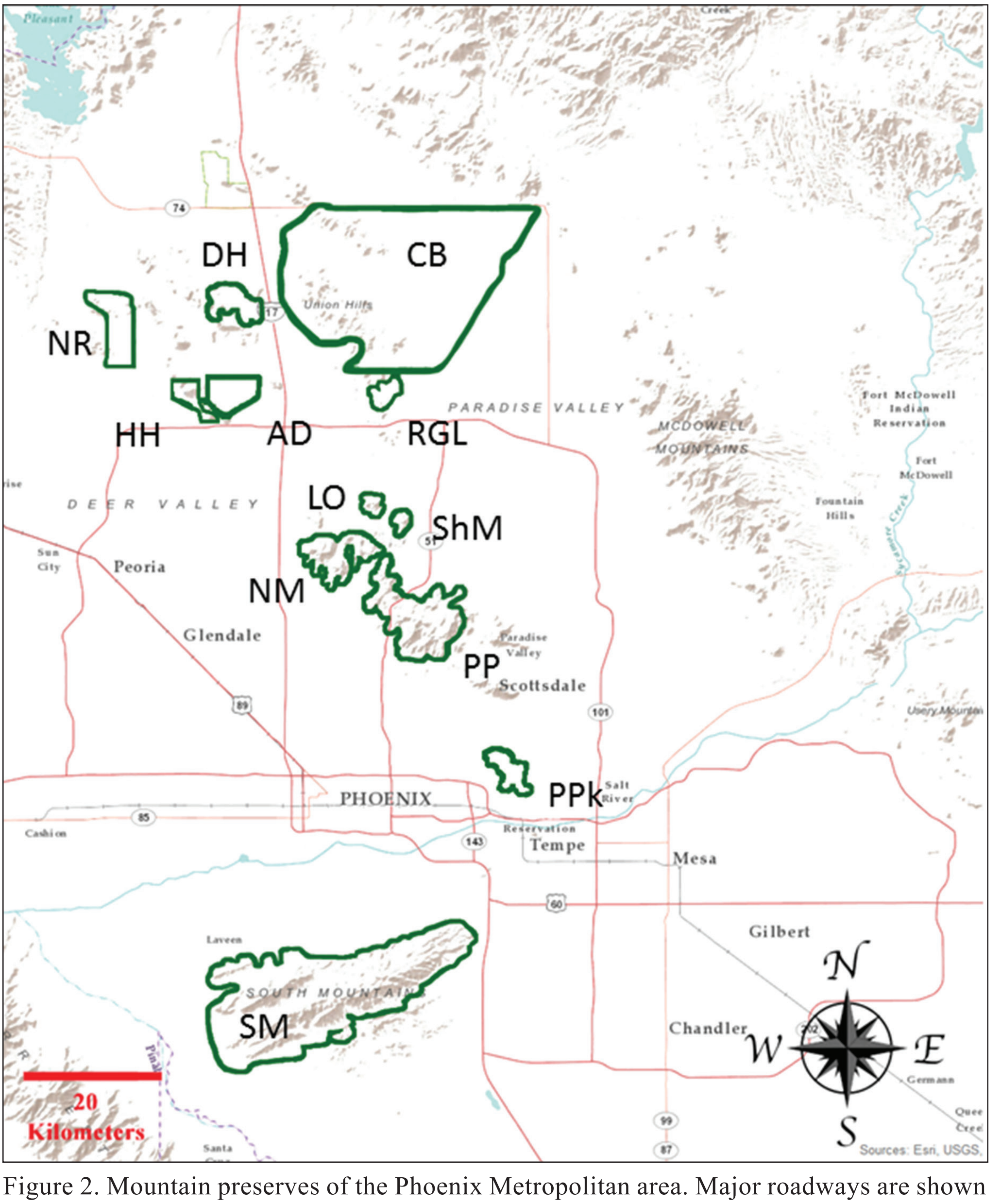


Figure 2. Mountain preserves of the Phoenix Metropolitan area. Major roadways are shown in red and major cities are labeled, and survey sites indicated by abbreviations defined in the text.

estimates were gathered for other sites visited in the course of other studies described above. In those surveys, species were recorded in daily field notes, but no data were gathered concerning relative abundances of lizards observed.

To maximize detection of lizards, surveys were conducted during warm weather (air temperature = 18–30 °C) from spring (March) through the fall (October), after which lizard activity drops off dramatically, and were opportunistically undertaken when weather conditions had been optimal for lizard activity over the prior two days to avoid variation in abundance associated with shifts in activity due to inclement weather. These same practices were used by Sullivan and Flowers (1998). The entire area of open habitat ("flats") was surveyed by walking in parallel lines 15 m apart in smaller preserves (≥2 ha); in larger preserves, areas adjacent to trails were selected based on historical records for horned lizards (1990–2000 obtained in other work; Sullivan et al. 2014), to maximize the opportunity that these and other open-habitat lizards could be detected. Because trails leading to areas of flats in preserves always passed through rocky slopes and washes, these latter habitats were sampled incidentally to the focus on flats. In preserves with more than 2 ha of flats, VES surveys were terminated after 60 min. Repeat surveys covered the same area in each preserve. Direct observations of each species were required of all forms except Regal Horned Lizards, the only species in the Phoenix area reliably identifiable by its unique fecal pellets (Sullivan et al. 2014); thus, indirect sign was used for this one species at some sites (2 of 12). At the conclusion of five surveys, a preserve received a "presence" score if a lizard of a given species had been observed and a total abundance score by summing all lizards seen of each species.

A second means of gathering information on the presence or absence of lizards at each site was through work on other organisms, including monitoring of toads and tortoises (e.g., *Gopherus morafkai* Murphy, Berry, Edwards, Leviton, Lathrop and Riedle [Sonoran Desert Tortoise]). During these other field activities, incidental observations were obtained on any lizards observed. At CB, all lizards observed along a 4-km stretch of roadway (paved and unpaved), including a small number of surveys in the early evening, were counted and recorded on 20 days each year to provide a rough estimate of relative abundance of the species present at that site, for comparative purposes. Road-riding is an established method for assessing the diversity and abundance of squamate communities (Sullivan 2000, 2012); evening surveys for amphibians at two sites, CB and SM, allowed observation of *Coleonyx variegatus* (Baird) (Western Banded Gecko) and Regal Horned Lizards, active just after sunset in the Sonoran Desert. Surveys for snakes, using an array of coverboards under which they take refuge, were also used in lizard tallies for the CB site because Banded Geckos and some other species sought shelter under the coverboards well. Efforts at these four sites—AD (20 surveys), CB (158 surveys), LO (32 surveys), and SM (151 surveys)—allowed large samples for a more accurate assessment of variation in abundances of each species across preserves relative to the more limited surveys across all preserves.

We calculated Shannon-Weaver and adjusted Simpson (i.e., reciprocal) diversity indices, following the equations provided by Cross et al. (2012), to compare species richness (i.e., diversity) and evenness for sites with large numbers of observations across all taxa (i.e., >200 observations across species: AD, CB, LO, and SM). These same values were derived from data provided in prior studies of the Phoenix (Banville and Bateman 2012, Parker 1967) and Tucson (Germaine and Wakeling 2001) areas. For these analyses, we used survey results for diurnal forms alone, excluding the small number of Western Banded Geckos detected at two of our sites by use of road-riding at night (i.e., CB and SM), and those found by Parker (1967) using pitfall traps.

Because of small sample sizes, especially for historical comparisons (i.e., the five primary sites surveyed by Sullivan and Flowers [1998]), we used nonparametric statistical tests exclusively (following Hollander and Wolfe 1973, Zar 1999). We used Spearman's rho (nonparametric correlation) to assess relationships among independent (e.g., size of preserve) and dependent (e.g., species counts) variables, and Wilcoxon signed-ranks, matched-pairs tests to assess shifts in both diversity and abundance at sites across sampling time periods. Tests were conducted using SPSS (version 20.0, SPSS for Windows, Rel. 20.0.0, 2011; SPSS, Inc., Chicago, IL).

## Results

Lizard diversity within the 12 interior preserves ranged from three to nine species during both the 1990s and the 2010s (Table 1). The four outlying parks selected for baseline comparisons exhibited significantly higher species richness, ranging from 10 to 13 species (Mann-Whitney U, Z = 2.98, $P = 0.003$, $n = 16$).

The five preserves surveyed in the mid-1990s (LO, NM, PP, ShM, and SM) by Sullivan and Flowers (1998), and the one (HH) by Sullivan and Williams (2010), retained the same species richness and abundance of lizards in more recent surveys during the 2010s (Table 1), except for the loss of a single species at one site. The only species historically present but undetected during our surveys in the 2010s was the Regal Horned Lizard in the PP site (evidence presented elsewhere indicates it has been absent from this site since 1998; see Sullivan et al. 2014). Using data from those five sites in addition to data from the two flood-control sites (AD, CB) and a third site (HH), species richness did not vary across time periods (Wilcoxon matched-pairs, signed ranks: Z = 1.73, $P = 0.083$, $n = 8$ sites), nor did abundance (Wilcoxon matched-pairs, signed ranks: Z = 0.75, $P = 0.462$, $n = 6$ sites).

Though there was not a significant shift in species richness overall, one species detected at the two flood-control sites, the Desert Iguana (AD = one individual in 1994, CB = one individual in 1990), has not been detected there since (neither during incidental work through the 1990s, nor during thousands of hours of fieldwork since 2010). Desert Iguanas were observed at the NR site and the edge of the SM site in the more recent surveys (2011–2014 for NR, 2010–2011 for SM; Appendix 1). Only a single Desert Iguana was observed at the SM site in the mid-1990s, and the 2010s.

There was a significant positive relationship for the current species counts and preserve size ($r_s = 0.72$, $n = 12$, $P < 0.02$). Thus, larger preserves exhibited more speciose lizard communities; there was no relationship with abundances of lizard counts overall (r = 0.23, $n$ = 10, $P > 0.20$). *Uta stansburiana* Baird and Girard (Common Side-blotched Lizard) were numerically dominant at three of the four intensively surveyed sites (Table 2), and *Aspidoscelis tigris* (Baird and Girard) (Tiger Whiptail) were ranked first or second in relative abundance across all four intensively surveyed sites (Table 2). Five species accounted for the vast majority of lizard observations overall (Table 2, Fig. 3). The average number of lizards (all species, summed) observed during each of the 60-minute VES surveys varied widely across preserves (from 5–36 lizards; Table 1).

For sites with extensive survey results across all species, exclusive of the nocturnal geckos, Shannon-Weaver diversity indices varied from 0.55 for the low diversity, highly uneven LO site dominated by Common Side-blotched Lizards (~90% of all lizards observed), to a high of 2.45 for the relatively more even (no species accounted for >30% of lizards observed) and diverse SM site (Tables 2, 3). Similarly, the Simpson's index varied from a low of 0.61 (LO) to a high of 2.61 (SM), precisely parallel to the Shannon-Weaver values (Table 3).

Table 2. Abundance of lizards (see Appendix 1 for abbreviations) observed at four sites (AD = 20 surveys, CB = 158 surveys, LO = 32 surveys, SM = 151 surveys), 2010–2014, from all survey methods combined.

| | Adobe Dam | | Cave Buttes | | Lookout | | South Mtn | |
|---|---|---|---|---|---|---|---|---|
| Species | *n* | % | *n* | % | *n* | % | *n* | % |
| UTST | 239 | 69% | 3352 | 65% | 675 | 90% | 324 | 14% |
| ASTI | 69 | 20% | 829 | 16% | 51 | 7% | 618 | 30% |
| CADR | 8 | 2% | 632 | 12% | 0 | - | 530 | 23% |
| SCMA | 6 | 2% | 279 | 5% | 0 | - | 107 | 5% |
| SAAT | 21 | 6% | 5 | <1% | 23 | 3% | 471 | 20% |
| PHSO | 5 | 1% | 14 | <1% | 0 | - | 1* | <1% |
| COVA | 0 | - | 23 | <1% | 0 | - | 31 | 1% |
| UROR | 0 | - | 0 | - | 0 | | 324 | 14% |
| Totals | 348 | | 5134 | | 749 | | 2351 | |

*Based on fecal counts

Table 3. Shannon-Weaver and Simpson (reciprocal) diversity indices for three prior studies and four sites (AD = 20 surveys; CB = 158 surveys; LO = 32 surveys; SM = 151 surveys) from the present study. All values exclusive of the nocturnal Western Banded Gecko (COVA). "T" = Tucson; "P-R" = Phoenix, riparian habitats; AD = Adobe Dam, CB = Cave Buttes, LO = Lookout, and SM = South Mountain Preserve.

| Diversity | Total observ. | Shannon-Weaver | Simpson | Site and Study |
|---|---|---|---|---|
| 6 | 348 | 1.39 | 0.97 | AD: this study |
| 6 | 5111 | 1.47 | 1.06 | CB: this study |
| 3 | 749 | 0.55 | 0.61 | LO: this study |
| 8 | 2320 | 2.45 | 2.56 | SM: this study |
| 9 | 349 | 1.98 | 1.41 | T: Germaine and Wakeling 2001 |
| 7 | 83 | 2.43 | 2.42 | P-R: Banville and Bateman 2012 |
| 8 | 472 | 1.84 | 1.30 | SM: Parker 1967 |

## Discussion

### Historical diversity and abundance

One of the sites we surveyed, SM, was sampled extensively in the 1960s (Parker 1967). Species richness and evenness remains unchanged 50 years later (Table 3). Parker (1967) established five sampling sites at the eastern edge of SM using pit-fall traps, which capture lizards that take refuge under covers over open traps. We observed all nine of the species he trapped at his five pit-fall sites in the 1960s (Table 2, Appendix 1). However, Parker observed a tenth species, Long-nosed Leopard Lizard, in the vicinity of his eastern-most traps, an area which since has been replaced by a golf course and housing. His photographs reveal the habitat in the vicinity of his eastern-most sites (1 and 2; see Parker 1967) was sandy, open Creosote flats not unlike the Salt River floodplain less than 2 km to the north. All of the sites sampled by Parker that remain intact (i.e., those to the west, his sites 3–5) within the boundaries of the preserve retain the same level of diversity documented in our more recent surveys (Table 1, Appendix 1). Interestingly, though species richness was equal, the diversity indices derived from Parker's pit-fall trap surveys were somewhat lower than those calculated from our VES surveys (Table 3). This difference was a result of the relative unevenness of his data (i.e., variation in abundance values), due in part to his methods failing to document higher numbers

Figure 3. The five most abundant lizards of mountain preserves in the Phoenix metropolitan region: Tiger Whiptail (ASTI; upper left), Zebra-tailed Lizard (CADR; upper right), Desert Spiny Lizard (SCMA; lower left), and Side-blotched Lizard (UTST; lower center) and Common Chuckwalla (SAAT; lower right).

of rock-dwelling forms (Common Chuckwalla and *Urosaurus ornatus* Baird and Girard [Ornate Tree Lizard]) we observed regularly, as well as his surveys having exceptionally large numbers of nocturnal, ground-dwelling geckos (Western Banded Gecko), to be expected with pit-fall traps.

The results from other preserves surveyed by Sullivan and Flowers (1998) in the mid-1990s are largely similar in diversity and abundance of lizards present to those from the 2010s, save for the loss of one species of horned lizard from one preserve surveyed historically. Given that horned lizards occupied a very small area of the PP preserve (<2 ha), it is perhaps unsurprising that the apparent change in availability of their prey that Sullivan and Flowers (1998) noted could have significant consequences. Regal Horned Lizards are still present at the SM site, as are their prey, seed harvester ants (Sullivan et al. 2014). Loss of one species may be viewed as inconsequential, but it does represent a 17% decrease in the original lizard diversity of the PP site in only twenty years (see review in Sullivan et al. 2014). Those intervening twenty years comprise impacts by recreational users, reptile collectors, and heat-island effects, to list only three (see review of these factors in Sullivan et al. 2013). The smallest preserves, LO and ShM, have not lost any additional species, but neither have most other preserves. Last, no preserves have been recently occupied by either native or non-native taxa, as apparently occurred at the Desert Botanical Garden in southeast Phoenix following the introduction of *Sceloporus magister* Hallowell (Desert Spiny Lizard) in the 1960s (Barnes 1992, Feldman 1978), and in southern Mesa on the eastern edge of the Phoenix metropolitan area with the introduction of *Chalcides ocellatus* Forsskål (Ocellated Skink) in the 1990s (Gunn et al. 2012).

The absence of Desert Iguanas since the mid-1990s at the AD and CB sites is potentially troubling. Surveys for Desert Iguanas over the past ten years allow us to offer a more nuanced explanation for variation in the distribution of species in the Phoenix region and its absence from the CB area and the newly established Sonoran Preserve to the immediate west (see below). Detection of Desert Iguanas at the AD and CB sites were based on single individuals observed at each site in the early 1990s: no additional specimens were ever observed, either in the 1990s, or during hundreds of hours of observation and surveys from 2009–2014. Surprisingly, Desert Iguanas have been consistently observed in highly disturbed riparian corridors along the New River 6 km west of the AD site (Fig. 4) and the Salt River along the boundary of the SM site. These observations reveal a pattern of occurrence in which Desert Iguanas are found in the sandy soils associated with floodplains of the Salt and Gila rivers and their tributaries (e.g., Agua Fria, New River, Skunk Creek, Cave Creek; see Banville and Bateman 2012 and Sullivan and Vernon, in press). As one progresses northward along these riparian corridors, in even highly disturbed habitats, one can still observe iguanas in some locations, though they have undoubtedly declined in numbers due to some development. The single individuals observed in the early 1990s, at AD (Skunk Creek) and CB (Cave Creek) may represent the naturally occurring local northern distributional limit of this lizard in the Phoenix region. Thus, this species may not have been lost from these northern sites over the subsequent 20 years; rather, it may have never been established this far to the north. This perspective is supported by the ease with which this species can be observed at sites further to the south along the Agua Fria and New rivers in western Phoenix (Fig. 4). In the absence of a distributional "limit" to explain the absence of this lizard from the expansive Creosote flats of the CB site (>10 km$^2$), their loss from this relatively undisturbed habitat is inexplicable at present.

Our observations of relatively low-diversity communities at the smallest preserves are consistent with the notion that habitat patch size influences community-level species richness and diversity deterministically, as suggested for reptile communities on mountain tops in the Southwest (Jones et al. 1985) and

Figure 4. Desert Iguana (DIDO) in urbanized landscape, adjacent to the New River, in northwestern Phoenix. The roadside lot is shown to the top left panel (note lizard on top of gate, leftside), a closeup of the lizard is shown on the upper right panel, and the lower panel.

birds of desert (Litteral and Wu 2012) and urban (Davis et al. 2013) areas. Under this view, the original habitat variation encompassed by the urban preserves determined the diversity of lizards present. Additionally, it may be that our resurvey interval was too short, and that additional species will be lost over time, especially if they are more long-lived than is widely appreciated. For example, Common Chuckwallas persist at the LO site even though population density is the lowest of all populations studied to date (Sullivan and Sullivan 2012). Given these lizards live to over thirty years of age, our survey intervals may have been too short to detect the loss of this species.

**Current diversity and abundance**

The urban preserve sites we surveyed ranged in diversity from three to nine species, which is low compared with the known diversity of the adjacent Sonoran Desert (Table 1; Jones et al. 1985, Parker 1967). The observation that larger preserves have higher diversity is consistent with the traditional species-area relationship that larger islands of habitat with (presumably) higher habitat diversity should support more diverse communities (see reviews in Buckley and Jetz 2010, Davis et al. 2013, Farnsworth et al. 2014). This hypothesis was corroborated by work on mountain top (i.e., higher elevation) communities of squamate reptiles across the Sonoran Desert by Jones et al. (1985). They found that the diversity of species found in non-desert habitats (e.g., chaparral and desert grassland biomes) was strongly predicted by the size of those habitats present at higher elevation on mountain tops in a "sea" of desert habitat. A positive influence of area on diversity is widely established for a number of taxa, including birds of the Sonoran Desert (Litteral and Wu 2012) and Western Australia (Davis et al. 2013).

Banville and Bateman (2012) found that for three riparian sites along the Salt River running east–west across the southern Phoenix Metropolitan region, Tiger Whiptails (25%) and Side-blotched Lizards (33%) were numerically dominant across the lizard community of seven species, which included both the Desert Iguana and a riparian-corridor specialist, *Urosaurus graciosus* (Hallowell) (Long-tailed Brush Lizard), that was otherwise absent from the entire Phoenix area (Brennan and Holycross 2005). They suggested that increased vegetational complexity explained variation in the diversity of lizards in the riparian sites they sampled, consistent with the overall notion that habitat complexity in part explains the variation in preserve diversity we documented. Shannon-Weaver and Simpson diversity indices for their study (SW = 2.43, S = 2.42, $n$ = 83 lizards total; Table 3) were relatively high but within the range of values we obtained across our four most extensively surveyed sites; similar results were obtained for Parker's study of SM from the 1960s and Germaine and Wakeling's (2001) study of the Tucson area in the late 1990s (Table 3). Considering the results of the aforementioned studies together, we infer that the Phoenix area preserves are somewhat lower in species diversity and evenness relative to outlying areas of the Sonoran Desert, but within the range of urban riparian sites in the Phoenix area, and the entire urban region of the much smaller Tucson metropolitan area.

The relative abundance of taxa across the range of size of preserves, from one of the smallest, LO, to one of the largest, CB, reveals that one lizard virtually absent from most of the developed metropolitan region, the Side-blotched Lizard, is the predominate species among the lizard communities of preserves, representing a minimum of 65% of all lizards seen and as much as 90% of lizards in the lower-diversity sites (i.e., LO; Table 2). The relative ranking in abundance across the four most intensively surveyed sites reveals that Side-botched Lizard and Tiger Whiptail are the most abundant lizard species in the preserve communities, together accounting for 80–95% of lizards observed. Interestingly, across the vast majority of the metropolitan area apart from remnant habitat patches, Side-blotched Lizards have been lost, presumably as a result of their ground-dwelling habits and vulnerability to predators (e.g., *Felis catus* L. [Domestic Cat]) and anthropogenic habitat change favoring arboreal species (e.g., OrnateTree Lizard) now found throughout the urban landscape (Ackley et al. 2015, Germaine and Wakling 2001). The riparian communities surveyed by Banville and Bateman (2012) were also dominated by this same pair of lizard species (58% of all lizards they observed).

The exception to numerical dominance by Side-blotched Lizards was the SM site. This preserve was relatively more even, as indicated by the highest values of diversity indices (also associated with the higher species richness observe therein), with higher numbers of saxicolous lizards, both Common Chuckwallas, rock-crevice–dwelling specialists, and Tree Lizards, rock- or tree-dwelling specialists. At this site, Side-blotched Lizards composed only 15% of the lizards observed, and Tree Lizards, entirely absent from the other three extensively surveyed sites, together with Common Chuckwallas, accounted for over 34% of all lizards observed. Tiger Whiptails, the second most abundant lizard in most preserves, dominated the SM site (Table 2); along with Tree Lizards, Tiger Whiptails are one of the two lizards occupying highly impacted urbanized landscapes over much of Phoenix (Ackley et al. 2015). Whiptails dominated the urban surveys (55% of all lizards seen) in the Tucson area in a study of the lizard community there in the late 1990s, while Side-blotched Lizards were exceedingly rare (<1%) (Germaine and Wakeling 2001). The somewhat contrasting indices of our surveys at SM and those of Parker in the 1960s highlight the importance of sampling methods, all of which have inherent biases depending on the behavioral ecology of the target organisms.

## Conclusions

In the early 1990s, one of us (B.K. Sullivan) served as a consultant to the Phoenix Parks Department regarding planning for a large preserve on the northern edge of the Phoenix Metropolitan area (Burke and Ewan 1999). One of the primary recommendations was that future preserves should include both open flats (Creosote-Bursage valleys) and xeric washes (Palo Verde-Ironwood-Acacia) to increase the habitat heterogeneity relative to that of the interior mountain preserves established over the previous five decades. This recommendation was based in part on the presumption that the addition of these habitats would result in the presence of a variety of reptiles lacking from the interior preserves (i.e., Desert Iguanas, Long-nosed Leopard Lizards, Regal Horned Lizards, and Desert Horned Lizards), subsequently reinforced by the work of Sullivan and Flowers (1998). Sullivan and Flowers (1998) may have wrongly assumed that the community of Sonoran Desert flats, dominated by Creosote and Bursage, was more uniform across the southern portion of the state than was advisable. The prediction of a more diverse lizard community was not to be: the area that was eventually preserved (Sonoran Preserve Park in 2009, adjacent to the CB site) is roughly similar in diversity to other mid-sized preserves (6 species) rather than to the outlying sites (10–13 species) or even the similarly sized SM site (9 species). Surprisingly, inclusion of a large area of flats did not increase the diversity of reptiles, most likely because of historical contingencies in the respective distributions of these lizards. These results suggest that there is no substitute for detailed natural history information on the local distribution of taxa in conservation planning for preserves.

## Acknowledgments

We thank Leah Kapa and Daniel, Justin, and Elizabeth Sullivan for assistance in the field. Observations were conducted under authority of permits provided by the Arizona Game and Fish Department (AGFD). Collecting methods were approved as part of an IACUC protocol (B.K. Sullivan) for surveying reptiles and amphibians. Maricopa County Flood Control personnel, especially Dennis Duffy, Dianna Cunningham, and Diana Stuart, provided considerable assistance at the CB site, as did Rob Patterson and Andy Long of the Phoenix Parks Department, and Roger Moncayo provided assistance with site protection. A number of individuals have helped clarify our thinking about urban impacts and desert lizards: Jeff Ackley, John Alcock, Dale DeNardo, Tom Jones, Matt Kwiatkowski, and Jianguo Wu were helpful in the development of our study, while Bob Bezy, Tom Gatz, and Gillian Rice assisted during the preparation of our manuscript.

## Literature Cited

Ackley, J., J. Wu, M. Angilletta, S. Myint, D. DeNardo, and B.K. Sullivan. In press. Rich lizards: How affluence and land cover influence the diversity and abundance of desert reptiles persisting in an urban landscape. Biological Conservation.

Banville, M., and H.L. Bateman. 2012. Urban and wildland herpetofauna communities and riparian microhabitats along the Salt River, Arizona. Urban Ecosystems 15:473–488.

Barnes, R. 1992. Springtime offers chance for a look into lizard lives. The Sonoran Quarterly 46(1):1–4.

Barrows, C.W., K.L. Prestion, J.T. Rotenberry, and M.F. Allen. 2008. Using occurrence records to model historic distributions and estimate habitat losses for two psammophilic lizards. Biological Conservation 141:1885–1893.

Brennan, T.C., and A.T. Holycross. 2005. Amphibians and reptiles of Maricopa County. Arizona Game and Fish Department, Phoenix, AZ, USA. 68 pp.

Buckley, L.B., and W. Jetz. 2010. Lizard community structure along environmental gradients. Journal of Animal Ecology 79:358–365.

Burke, J., and J. Ewan. 1999. Sonoran Preserve Master Plan: An open-space plan for the Phoenix Sonoran Desert (17 February 1998). City of Phoenix Parks, Recreation and Library Department, Pheonix, AZ, USA. Pp. 1–51.

Cross, C.L., N. Ananjeva, N.L. Orlov, and A.W. Salas. 2012. Parametric analysis of reptile biodiversity data. Pp. 273–282, *In* R.W. McDiarmid, M.S. Foster, C. Guyer, J.W. Gibbons, and N. Chernoff (Eds.). Reptile Biodiversity: Standard Methods for Inventory and Monitoring. University of California Press, Berkeley, CA, USA. 412 pp.

Davis, R.A., C. Gole, and J.D. Roberts. 2013. Impacts of urbanization on the native avifauna of Perth, Western Australia. Urban Ecosystems 16:427–452.

Esbah, H., E.A. Cook, and J. Ewan. 2009. Effects of increasing urbanization on the ecological integrity of open space preserves. Environmental Management 43:846–862.

Farnsworth, L.M., D.G. Nimmo, L.T. Kelly, A.F. Bennett, and M.F. Clarke. 2014. Does pyrodiversity beget alpha, beta, or gamma diversity? A case study using reptiles from semi-arid Australia. Diversity and Distributions 20:663–673.

Feldman, B. 1978. The garden's lizards. Saguaroland Bulletin August–September:76–78.

Fischer, J., D.B. Lindenmayer, S. Barry, and E. Flowers. 2005. Lizard distribution patterns in the Turmut fragmentation "Natural Experiment" in southeastern Australia. Biological Conservation 123:301–315.

Fisher, R.N., A.V. Suarez, and T.J. Case. 2002. Spatial patterns in the abundance of the Coastal Horned Lizard. Conservation Biology 16:205–215.

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 178:997–1005.

Germaine, S.S., and B.F. Wakeling. 2001. Lizard species distributions and habitat occupation along an urban gradient in Tucson, Arizona, USA. Biological Conservation 97:229–237.

Garden, J.G., C.A. McAlpine, H.P. Possingham, and D.N. Jones. 2007. Habitat structure is more important than vegetation composition for local-level management of native terrestrial reptile and small mammal species living in urban remnants: A case study from Brisbane. Austral Ecology 32:669–685.

Gunn, J., R.W. Bowker, K.O. Sullivan, and B.K. Sullivan. 2012. An Old World skink, *Chalcides ocellatus*, with a long history of anthropogenically assisted dispersal, now established in Mesa, Arizona, USA. Herpetological Review 43:551–553.

Hollander, M., and D.A. Wolfe. 1973. Nonparametric Statistical Methods. John Wiley and Sons, New York, NY, USA.

Jennings, M.R. 1987. Impact of the curio trade for San Diego Horned Lizards (*Phrynosoma coronatum blainvillii*) in the Los Angeles Basin, California: 1885–1930. Journal of Herpetology 21:356–358.

Jones, K.B., L.P. Kepner, and T.E. Martin. 1985. Species of reptiles occupying habitat islands in western Arizona: A deterministic assemblage. Oecologia 66:595–601.

Jones, T.R., R.D. Babb, F. Hensley, C. LiWanPo, and B.K. Sullivan. 2011. Sonoran Desert snake communities at two sites: Concordance and effect of increased road traffic. Herpetogical Conservation and Biology 6:61–71.

Kane, K., J. Tuccillo, A.M. York, L. Gentile, and Y. Ouyang. 2014. A spatio-temporal view of historical growth in Phoenix, Arizona, USA. Landscape and Urban Planning 121:70–80.

Kitchner, D.J., A. Chapman, J. Dell, and B.G. Muir. 1980. Lizard assemblage and reserve size and structure in the western Australian wheatbelt—Some implications for conservation. Biological Conservation 17:25–62.

Koenig, J., R. Shine, and G. Shea. 2001. The ecology of an Australian Reptile icon: How do Blue-tongued Lizards (*Tiliqua scincoides*) survive in suburbia? Wildlife Research 28:215–227.

Litteral, J., and J. Wu 2012. Urban landscape matrix affects avian diversity in remnant vegetation fragments: Evidence from the Phoenix metropolitan region, USA. Urban Ecosystems 15:939–959.

MacNally, R., and G.W. Brown. 2001. Reptiles and habitat fragmentation in the box-iron-bark forests of central Victoria, Australia: Predictions, compositional change and faunal nestedness. Oecologia 128:116–125.

Martin, J., and P. Lopez. 2002. The effect of Mediterranean dehesa management on lizard distribution and conservation. Biological Conservation 108:213–219.

Parker, W.S. 1967. Ecological studies of lizards at South Mountain Park, Phoenix, Arizona. M.Sc. Thesis. Arizona State University, Phoenix, AZ. 122 pp.

Santos, T., J.A. Diaz, J. Perez-Tris, R. Carbonell, and J.L. Telleria. 2008. Habitat quality predicts the distribution of a lizard in fragmented woodlands better than habitat fragmentation. Animal Conservation 11:46–56.

Sarre, S., G.T. Smith, and J.A. Meyers. 1995. Persistence of two species of gecko (*Oedura reticulata* and *Gehyra variegata*) in remnant habitat. Biological Conservation 71:25–33.

Sherbrooke, W.C. 1981. Horned lizards: Unique reptiles of western North America. Southwest Parks and Monuments Association, Globe, AZ, USA.

Sherbrooke, W.C. 2003. Introduction to the Horned Lizards of North America. University of California Press, Berkeley, CA, USA.

Sullivan, B.K. 2000. Long-term shifts in snake populations: A California site revisited. Biological Conservation 94:321–325.

Sullivan, B.K. 2012. Road riding. Pp. 215–218, *In* R.W. McDiarmid, M.S. Foster, C. Guyer, J. W. Gibbons, and N. Chernoff (Eds.). 2. University of California Press, Berkeley, CA, USA. 412 pp.

Sullivan, B.K., and P.J. Fernandez. 1999. Breeding activity, estimated age-structure, and growth in Sonoran Desert anurans. Herpetologica 55:334–343.

Sullivan, B.K., and M. Flowers. 1998. Large iguanid lizards of urban mountain preserves in northern Phoenix, Arizona. Herpetological Natural History 6(1):13–22.

Sullivan, B.K., and M.A. Kwiatkowski. 2007. Courtship displays in anurans and lizards: Theoretical and empirical contributions to our understanding of costs and selection on males due to female choice. Functional Ecology 21:666–675.

Sullivan, B.K., and K.O. Sullivan. 2008. Common Chuckwalla (*Sauromalus ater*) populations in the Phoenix Metropolitan area: Stability in urban preserves. Herpetological Conservation and Biology 3:149–154.

Sullivan, B.K., and K.O. Sullivan. 2012. Common Chuckwalla (*Sauromalus ater*) in an urban preserve: Persistence of a small population and estimation of longevity. Herpetological Conservation and Biology 7:437–441.

Sullivan, B.K., and J.E. Vernon. In press. Desert Iguanas (*Dipsosaurus dorsalis*) in urban landscapes: Natural history observations. Herpetogical Review.

Sullivan, B.K., and R.E. Williams. 2010. Common Chuckwallas (*Sauromalus ater*) in urban preserves: Do food plants or crevice retreats influence abundance? Herpetogical Conservation and Biology 5:102–110.

Sullivan, B.K., M.A. Kwiatkowski, and G.W. Schuett. 2004. Translocation of urban Gila Monsters: A problematic conservation tool. Biological Conservation 117(3):235–242.

Sullivan, B.K., R. Vanhaverbeke, and C. Chambers. 2013. Wildlife and anthropogenic changes in the arid Southwest. Pp. 169–191, *In* R. Malloy, J. Brock, A. Floyd, M. Livingston, and R.H. Webb (Eds.). Design with the Desert: Conservation and Sustainable Development. CRC Press, Boca Raton, FL, USA. [Peer-reviewed].

Sullivan, B.K., K.O. Sullivan, D.E. Vardukyan, and T.S. Suminski. 2014. Persistence of horned lizards (*Phrynosoma* spp.) in urban preserves of central Arizona. Urban Ecosystems 17:707–717.

Trubl, P., T. Gburek, L. Miles, and J.C. Johnson 2011. Black Widow Spiders in an urban desert: Population variation in an arthropod pest across metropolitan Phoenix, AZ. Urban Ecosystems 15:599–609.

Zar, J.H. 1999. Biostatistical Analysis, 4th Edition. Prentice Hall, Upper Saddle River, NJ, USA.

**Appendix 1**. Lizards observed in Phoenix Metropolitan area during all survey periods, 1990–2014. Abbreviations in parentheses represent species names used elsewhere in the manuscript.

| Species | Sites |
|---|---|
| *Colenoyx variegatus* (Banded Gecko; COVA) | AD, CB, SM |
| *Sauromalus ater* (Chuckwalla; SAAT) | AD, CB, DH, HH, LO, NM, NR, PPk, RGL, ShM, SM |
| *Crotaphytus* spp. (Collared lizards) | - |
| *Phrynosoma platyrhinos* (Desert Horned Lizard) | - |
| *Dipsosaurus dorsalis* (Desert Iguana; DIDO) | NR, SM |
| *Sceloporus magister* (Desert Spiny Lizard; SCMA) | AD, CB, DH, NM, NR, PP, RGL, ShM, SM |
| *Heloderma suspectum* Cope (Gila Monster) | - |
| *Gambelia wislizenii* (Leopard Lizard) | - |
| *Phrynosoma solare* (Regal Horned Lizard; PHSO) | AD, CB, DH, PP, RGL, SM |
| *Uta stansburiana* (Common Side-blotched Lizard; UTST) | AD, CB, DH, HH, LO, NM, NR, PP, PPk, RGL, ShM, SM |
| *Aspidoscelis tigris* (Tiger Whiptail; ASTI) | AD, CB, DH, HH, LO, NM, NR, PP, PPk, RGL, ShM, SM |
| *Urosaurus ornatus* (Tree Lizard; UROR) | PP, SM |
| *Callisaurus draconoides* (Zebra-tailed Lizard; CADR) | AD, CB, DH, NR, PP*, RGL, SM* |

**Cophosaurus texanus* Troschel (Greater Earless Lizard) was erroneously listed for these two preserves ($n$ = 1 in each preserve) in Sullivan and Flowers (1998), but subsequently were determined to represent this taxon, *C. draconoides*.