

The conservation value of residential yards: linking birds and people

SUSANNAH B. LERMAN^{1,3} AND PAIGE S. WARREN²

¹Graduate Program in Organismic and Evolutionary Biology, University of Massachusetts, Amherst, Massachusetts 01003 USA

²Department of Natural Resources Conservation, University of Massachusetts, Amherst, Massachusetts 01003 USA

Abstract. Urbanization is recognized as one of the greatest threats to biodiversity throughout the world. However, the vegetation within an urbanized landscape is diverse and includes a variety of native and exotic plant species. This variation allows for testing whether certain landscape designs outperform others in the support of native biodiversity. Residential yards represent a large component of an urban landscape and, if managed collectively for birds and other wildlife, could offset some of the negative effects of urbanization. In addition, many urbanites have their primary interaction with the natural world in their front and back yards. Therefore, ensuring positive wildlife experiences for them is essential in promoting urban biodiversity. At the Central Arizona–Phoenix Long-Term Ecological Research site we tested the efficacy of native landscaping in residential yards in attracting native birds. We also explored the links between socioeconomic factors, landscape designs, and urban gradient measurements with the urban bird communities. A redundancy analysis suggested that native desert bird species increased in abundance in neighborhoods with desert landscaping designs, neighborhoods closer to large desert tracts, and higher-income neighborhoods. Variance partitioning showed that collectively these three sets of environmental variables explained almost 50% of the variation in the urban bird community. Results suggested racial and economic inequities in access to biodiversity, whereby predominantly Hispanic and lower-income neighborhoods had fewer native birds. We also found that residents' satisfaction with bird diversity was positively correlated with actual bird diversity. Our study provides new insights into the relative importance of socioeconomic variables and common urban ecological measurements in explaining urban bird communities. Urban planners can use this information to develop residential landscapes that support the well-being of both birds and people.

Key words: Arizona, USA; CAP LTER; human–wildlife interactions; long-term ecological research; native landscaping; residential yards; socio-ecology; urban birds.

INTRODUCTION

As our world becomes increasingly urbanized, understanding how to conserve biodiversity while creating landscapes compatible with humans is one of the century's greatest conservation challenges. It is estimated that by 2050, >80% of the world's population will live in urbanized areas (United Nations Population Fund 2007). A consequence of this mass migration to cities and their expansion is the loss of wildlife habitat and the creation of new plant communities (Whitney and Adams 1980), with profound implications for local and regional biodiversity (Smith et al. 2005, Shochat et al. 2006, Burghardt et al. 2009). Furthermore, there is a growing disconnect between people and nature with the loss of biodiversity in urban and suburban landscapes (Turner et al. 2004, Miller 2005). However, within urban areas, there is tremendous variation in both the composition and configuration of the vegetation, ranging from landscapes dominated by novel and

foreign vegetation with little or no shrubbery (Reichard and White 2001) to landscapes that include key features of the natural wildlands being replaced, including a mixture of native plants and a complex, multilayered vegetation structure. In light of the projected urban growth, we need to fully understand if landscape designs that resemble the wildlands can provide suitable habitat for native species, thus alleviating some of the detrimental impacts of urbanization on native biodiversity. In addition, we need to address more fully urban biodiversity in the context of human socioeconomic factors and explore ways to enhance human–wildlife experiences.

Using an urban gradient approach, previous urban bird studies have characterized the urban core as having lower diversity but higher densities compared with wildlands (e.g., Emlen 1974, Beissinger and Osborne 1982, Mills et al. 1989, Blair 1996, Marzluff 2001, Donnelly and Marzluff 2004, Chace and Walsh 2006, Croci et al. 2008). The patterns emerging from these studies suggest that people living close to the urban core will experience lower biodiversity. The amount and type of diversity leads to varying levels of positive human–nature interactions (Fuller et al. 2007). For example, people interacting in areas with high levels of native

Manuscript received 1 March 2010; revised 17 August 2010; accepted 25 August 2010; final version received 20 September 2010. Corresponding Editor: J. M. Marzluff.

³ E-mail: slerman@cns.umass.edu

diversity tend to have a stronger connection to a sense of place and a sense of belonging (Horowitz et al. 2001). In Sheffield, UK, researchers found a positive relationship between psychological well-being and species richness in urban open spaces (Fuller et al. 2007). To improve their access to biodiversity, people could move closer to rural areas characterized with higher diversity. However, for many urbanites this is not a viable option. Alternatively, people can improve local conditions for native biodiversity in private yards, gardens, and common spaces (Turner et al. 2004, Troy et al. 2007).

Residential yards and gardens represent a large percentage of urban land cover (Cannon 1999, Martin et al. 2003, Chamberlain et al. 2004), and if managed collectively, homeowners could provide habitat connectivity throughout urban areas (Rudd et al. 2002). In the United Kingdom, residential yards contain twice as much land as nature reserves (Chamberlain et al. 2004) and comprise 23% of the urban land area (Gaston et al. 2005). In Tucson, Arizona, USA, as much as 50% of high-density residential neighborhoods consisted of pervious (nonpavement) surfaces (Germaine et al. 1998), indicating the potential for improving urban and suburban areas by providing vegetation for wildlife habitat. A few studies have investigated vegetative diversity within residential yards, and they suggest that certain landscaping features improve native bird diversity. For example, in Hobart, Australia, yards with native plants had significantly more native birds than yards landscaped with exotic plants, though native birds did use gardens with some exotic trees and shrubs (Daniels and Kirkpatrick 2006). Burghardt et al. (2009) paired 12 residential yards in suburban Pennsylvania, USA, half landscaped with native plants and the other half with exotic plants, to investigate urban food webs and found that yards landscaped with native vegetation held the greatest numbers of butterfly larvae and insectivorous birds. Understanding how the vegetation variation within residential yards relates to urban bird distribution has important conservation consequences. If we can identify particular landscape designs that support native bird communities while discouraging synanthropic species, we may be able to improve the quality and quantity of habitat for species that often decline with urbanization (Warren et al. 2008).

Although the traditional urban gradient approach provides valuable information on urban bird patterns, many of these studies do not capture ecologically relevant variation in human socioeconomic characteristics beyond population density nor do they consider how the landscaped vegetation and socioeconomic factors can vary considerably at similar levels of urbanization and in areas classified as having the same land use (Kinzig et al. 2005). Supplementing urban gradient studies with vegetation structure measurements will inform us if certain landscape plantings can improve urban diversity throughout the urban gradient. Supplementing gradient studies with socioeconomic

variables within the same position on an urbanization gradient will inform us if access to biodiversity differs among socioeconomic groups. Empirical studies have found strong correlations between income levels and plant diversity (e.g., Hope et al. 2003, Kinzig et al. 2005, Smith et al. 2005, Kirkpatrick et al. 2007) and bird diversity (e.g., Kinzig et al. 2005, Melles 2005, Loss et al. 2009). Since humans are the primary driving force behind alterations to urban habitat, it becomes vital to include human variables in urban ecological studies (Adams 1935).

To our knowledge, this was the first study to address the impacts of human manipulation of urban habitat by testing the efficacy of native landscaping in residential yards for attracting native bird communities, while also integrating urban gradient measurements and socioeconomic factors into a multivariate analysis. Our novel, integrative, and interdisciplinary approach allowed us to highlight the relative importance of features that often are ignored in urban bird ecology studies and how these features are related to one another. We had two main study objectives. First, we explored the strengths of these environmental and socio-ecological associations with an urban bird community in residential yards. Within this framework we tested whether the variation in the existing bird diversity accords with human residents' perceptions of local bird diversity. Second, we calculated the total variance of the bird community explained by landscape plantings, urban gradient measurements, and socioeconomic factors, and we explored the relative importance of how these three features contribute to the patterns explaining urban bird communities.

METHODS

Study area

The Phoenix, Arizona, greater metropolitan area is located in the Salt River Valley, within the northern limits of the Sonoran Desert in the southwestern United States. Perennial vegetation is dominated by *Ambrosia deltoidea* (bursage), *Encelia farinosa* (brittle bush), *Larrea tridentata* (creosote bush), *Olneya tesota* (desert ironwood), *Parkinsonia florida* (blue palo verde), and *Prosopis juliflora* (mesquite) (Martin et al. 2004). Phoenix is the fifth largest American city, with a population of 1 300 000 (U.S. Census Bureau 2000), and the second fastest-growing American city, having doubled in population twice in the past 35 years. Conversion of desert and agricultural fields to residential landscapes occurs at a rate of >0.4 ha/h (Grimm and Redman 2004). Phoenix is dominated by two markedly different landscape designs: mesic (mixture of exotic, highly water-dependent vegetation and turf) and xeric (low water use shrubs, native or drought-tolerant vegetation, and gravel).

Study design

We conducted our study within the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER)

site. The CAP LTER study area consists of 204 long-term monitoring sites, covers 6400 km², and includes residential, commercial, agricultural, and desert land uses. The 204 sites were selected using a dual-density, randomized, tessellation-stratified design and measured plant, bird, and arthropod diversity, air and water quality, and human activity (Hope et al. 2003). Our study was part of the Phoenix Area Social Survey (PASS), a household survey that investigated opinions about quality of life and the condition of the natural environment. The PASS was conducted at 40 sites, drawn in a stratified sample from the 71 long-term monitoring sites of the CAP LTER that were in residential land use (Harlan et al. 2009). The survey sampled the neighborhood surrounding each of these 40 long-term monitoring sites. A neighborhood was defined as a U.S. census block group (Logan and Molotch 1987), and the 40 neighborhoods were stratified by income and distance from central Phoenix (Fig. 1). The stratification aimed to achieve equal representation for all possible combinations of spatial location (i.e., distance from the urban core) and human demographic types (defined by income, ethnicity and race, homeownership; Harlan et al. 2009) and was distributed across all municipalities in the Phoenix metropolitan region. This sample allowed us to test for independent effects of urbanization gradients and socioeconomic factors (Harlan et al. 2009).

Bird surveys

We surveyed birds at one site (the long-term monitoring site) for each of the 40 PASS neighborhoods (Fig. 1). The observer stood at plot center and recorded all birds seen and heard within a 15-min count period and within a 40-m radius (Ralph et al. 1993). We conducted the bird surveys over two years, encompassing two seasons of sampling per year: December 2006 and 2007 (winter season) and March 2007 and 2008 (spring season). Each site was visited by three different observers for each season each year, for a total of 12 visits per site for the entire study. Surveys were conducted within four hours of local sunrise and not conducted during heavy rain or when wind exceeded 32 km/h. To ensure that observed birds were using the local habitat, for all analyses we included only birds seen within 40 m of the plot center and omitted all birds flying through the plot. We combined the bird community data and calculated the maximum number of each species recorded per site over the 12 visits to portray accurately the year-round bird community (Melles 2005). We then classified the bird community into three major distribution categories. Global species included nonnative or alien invasive species introduced by humans, predominantly urban specialists (invasives). National species included widespread generalist species found in a variety of land use types throughout the United States and Canada (generalists). Regional

species included predominantly native Sonoran desert species (desert).

Habitat description

We measured vegetation along transects parallel to the road and quantified ground cover, trees, shrubs, and cacti in front yards using observational measurements to avoid trespassing. Although we acknowledged that front and back yards can differ greatly (Larsen and Harlan 2006), we focused on front yards because of ease of public access (Kirkpatrick et al. 2007). At each bird-monitoring site we conducted three 100 × 40 m habitat transects; one transect encompassed the bird-monitoring site with the point count at the transect center, and the remaining two transects were selected randomly within a 300-m radius from the bird-monitoring location. Transect size was based on the average home range or territory of 10 common Phoenix birds (transect length) and the amount of residential landscape visible from the road (transect width). The 300-m radius enabled us to determine the similarity of the vegetation at a scale potentially used for the birds documented at the bird-monitoring site (Germaine et al. 1998).

We measured key vegetation features generally thought to be important for urban desert birds. In particular, these features are representative of the characteristics of the mesic and xeric landscapes in Phoenix (Martin et al. 2003, Walker et al. 2009). For each transect we calculated the percentage of the yards with crushed gravel as a ground cover (xeric) or with turf ground cover (mesic). We classified trees using two methods. First, we categorized trees into five different leaf structures: conifer, broadleaf evergreen, broadleaf deciduous, monocot, and thin-leaf evergreen (Emlen 1974, Germaine et al. 1998). Thin-leaf evergreen trees are predominantly native or drought-tolerant trees typical of xeric designs, while trees in the other categories are generally water-dependent, exotic trees typical of mesic designs. We then binned the trees into three height classes (0–10 m, 10–20 m, >20 m). Native and drought-tolerant trees are predominantly <10 m, while the taller trees (e.g., monocots and conifers) tend to be exotic. We counted the total number of shrubs in two height classes (<1 m and >1 m) and cacti >1.5 m. The monocots, the majority of the broadleaf evergreens, and the cacti are fruit-bearing species and potentially provide important food sources for both desert and synanthropic birds. Since there were no significant differences between the three transects (one-way ANOVA, blocking by site, we pooled data across transects for each site and calculated mean abundances for each measured variable.

Socioeconomic variables

We used the census block group as our unit to describe the neighborhoods. The demographic characteristics within a census block group are assumed to be relatively homogeneous (Jenerette et al. 2007) and have

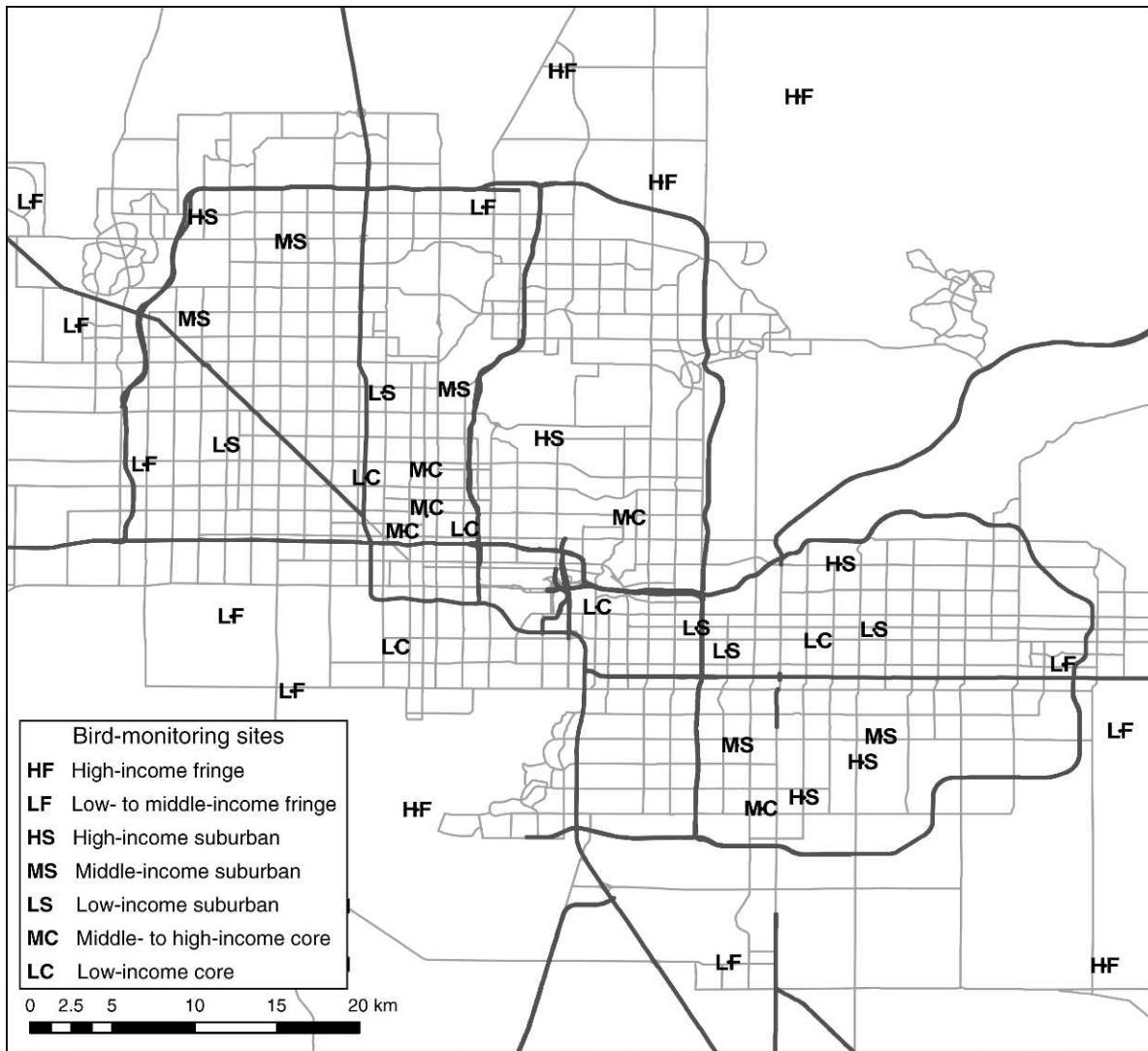


FIG. 1. The distribution of our bird-monitoring locations and neighborhoods within Phoenix, Arizona, USA. Bird-monitoring locations were stratified by income and distance to urban centers.

a population between 600 and 3000 people with a target size of 1500 (U.S. Census Bureau 2000). To represent ethnicity, socioeconomic status, and lifestyle stages of the residents from each neighborhood (Grove et al. 2006), we included the following socioeconomic variables from the 2000 U.S. Census: percent Hispanic, median household income, highest education degree obtained, percent owner occupation, and percent of residents age 0–18, 19–64, and ≥ 65 .

Urban gradient variables

Urban gradient measurements are surrogates for fragmentation, degree of urban development, and time since urban development. We included urban gradient features that we hypothesized to influence bird diversity (Kinzig et al. 2005). Along an urban gradient, we measured the amount of impervious surface, vegetation,

and soil around each bird-monitoring location, the distance from the bird-monitoring location to desert tracts, and the age of the neighborhood. We used remotely sensed measures of impervious surface, vegetation, and soil obtained from Quickbird images (DigitalGlobe, Longmont, Colorado, USA) using Imagine software (ERDAS 2006). The image resolution was 28.5 m. Impervious surface, bare soil, and vegetation around each bird-monitoring station were estimated as the mean percent cover per cell for a 2×2 km window (71×71 pixels), roughly encompassing a 1-km radius around the bird-monitoring center point. We measured the distance to desert tracts using ArcMap 9.2 geographic information system (ESRI 2006). To classify desert land use, we used a Landsat Enhanced Thematic Mapper land classification raster that used ERDAS Imagine software (ERDAS 2006) for analyses. This land

use land cover classification model has 12 land use categories, an overall kappa statistic of 0.81, and an overall accuracy of 83%. At each bird-monitoring center point we calculated the distance to the nearest desert tract of at least 3.2 ha. Our size of 3.2 ha reflects the average territory of the desert birds found within our study site and is similar to the continuous desert tracts used by Germaine et al. (1998) in Tucson, Arizona, USA. In addition, we calculated desert tracts of 42 ha following Donnelly and Marzluff's (2004) study showing that forest sizes >42 ha in Seattle, Washington, USA, retained most of the native forest specialist birds. Results from our statistical analyses using the two methods were similar. We used the median age of housing structures within each neighborhood from the 2000 U.S. Census, which is a surrogate for time since the initial urban development.

Phoenix Area Social Survey (PASS)

The Institute for Social Science Research at Arizona State University administered the PASS from April through September 2006. The survey team contacted 40 households within each of the 40 PASS neighborhoods and continued contacting these households until 20 households responded and agreed to participate in the survey. The response rate was 51%, and the study included 808 respondents. Surveys were taken on the Internet, on the telephone, and in personal interviews. Of the 111 questions in the survey, 14 addressed the level of satisfaction residents felt regarding the quality of their neighborhoods. For our study, we focused on two of the survey questions on biodiversity issues. Survey respondents were asked to rate the variety of birds in their existing neighborhood (satisfaction with bird variety in the neighborhood) and the variety of birds in their ideal neighborhood (desire for bird variety in the neighborhood). Ratings ranged from highly satisfied/desirable to highly unsatisfied/undesirable, respectively. We summarized ratings for each neighborhood by calculating the percentage of respondents who rated their actual and ideal bird variety as either highly or moderately satisfactory or desirable, respectively.

Statistical analysis

For the analyses, we omitted one neighborhood/bird-monitoring site because only a small percentage of the area in that neighborhood was residential. We assessed the relationships between our three subsets of environmental variables (habitat, socioeconomics, and urban gradient) and the bird community within each neighborhood using redundancy analysis (RDA). This multivariate ordination related the bird community data to the environmental data and depicted the patterns of variation within the bird community that could be explained by the environmental constraints (ter Braak 1986). We used RDA rather than Canonical Correspondence Analysis based on a preliminary assessment of the data: bird abundances demonstrated

a linear rather than unimodal response to the environmental gradients (gradient length <2 SD; ter Braak 1986). We reduced the number of bird species in the analysis by including only species recorded at $\geq 10\%$ of the monitoring locations. Multivariate analyses benefit from deleting rare species since species with few records are often not placed accurately in ecological space (McCune and Grace 2002), but we included all species for analyses involving total species richness. Since RDAs depend on redundancy within the dataset to summarize patterns in the community in the least number of dimensions (McGarigal et al. 2000), we conducted a global assessment of redundancy and redundancy for individual species within the data. We plotted the rank order distribution of pairwise species' correlations, and individual species against the null distribution obtained by randomly permuting the data. We omitted outliers to be sure a single observation did not have disproportional leverage on the results. These outliers consisted of extremely large flocks of a particular species (e.g., Mourning Dove), elevating the maximum count recorded during one of the 12 visits at a site. We log-transformed and then standardized the species data using a row relativization CHORD/NORMALIZE method to display the relative abundance profile for each site (Legendre and Gallagher 2001). This relativization preserves the Euclidean distances embedded in an RDA (Legendre and Gallagher 2001). The CHORD distance performed well when compared with other distance metrics. For the habitat, urban gradient, and socioeconomic matrices, we checked for multicollinearity among the variables. We computed a partial RDA for paired variables with correlations >0.7 and retained the variable with the largest marginal effect based on the constrained eigenvalue (McGarigal et al. 2000). We list the final variable selection in Table 1.

For the three RDAs (habitat, urban gradient, and socioeconomics) we calculated the proportion of the total inertia (or variance) of the species data explained by the environmental constraints. We tested the significance of the ordinations using Monte Carlo global permutation tests of significance (200 permutations) on the whole model, each axis, and each independent variable (Hope 1968). We calculated the standardized canonical coefficients. This calculation defines the variable's weight based on the linear combination that was used to constrain the ordination (McGarigal et al. 2000). We also calculated the intersite correlation coefficients. These represent the correlations between species-derived sample scores and the independent variables (i.e., species scores in environmental space) (McGarigal et al. 2000). Then we calculated the goodness of fit for individual species to ask how effective the ordination was at representing each species. This diagnostic feature reports the proportion of variance explained by the canonical axes for each species. We generated a triplot for each RDA to display graphically the bird community patterns and how they relate to the

TABLE 1. Independent variables used for the three redundancy analyses (habitat, urban gradient, socioeconomic variables) with descriptive statistics, standardized canonical coefficients, and interset correlation coefficients.

| Variable | Mean | SE | Range | | Standardized canonical coefficient | Interaset | | |
|---------------------------|---------|---------|--------|---------|------------------------------------|--------------------------|------------|--|
| | | | Low | High | | Correlation coefficients | <i>P</i> † | |
| Habitat | | | | | | | | |
| Shrubs | 18.74 | 2.17 | 5 | 60.67 | -0.11049 | -0.812 | <0.01 | |
| Broadleaf deciduous trees | 4.81 | 0.72 | 0 | 17 | 0.00307 | 0.36 | | |
| Broadleaf evergreen trees | 8.15 | 0.63 | 0 | 18.33 | 0.02056 | 0.349 | | |
| Conifers | 2.98 | 0.46 | 0 | 12 | 0.01444 | 0.445 | | |
| Thin-leaf evergreen trees | 7.7 | 1.81 | 0 | 64.67 | -0.05839 | -0.714 | | |
| Monocots | 7.15 | 7.15 | 0 | 23 | -0.04657 | 0.087 | | |
| Urban gradient | | | | | | | | |
| Soil (%) | 44.98 | 0.02 | 32.32 | 80.63 | -0.05116 | -0.6 | <0.01 | |
| Housing age (yr) | 1980 | 2.15 | 1950 | 1999 | 0.08109 | -0.589 | 0.04 | |
| Distance to desert (m) | 3765.98 | 526.73 | 12 | 12 217 | -0.07813 | 0.579 | | |
| Socioeconomic | | | | | | | | |
| Hispanic (%) | 24.2 | 3.89 | 0.29 | 87 | 0.05791 | 0.67 | <0.01 | |
| Income (\$) | 57 143 | 4411.18 | 21 750 | 120 368 | -0.10907 | -0.636 | | |
| Owner occupied (%) | 69.59 | 4.59 | 7 | 99.19 | 0.02189 | -0.514 | | |
| Age 65+ (%) | 15.18 | 3.17 | 0.65 | 84.57 | -0.04711 | -0.23 | 0.03 | |
| Bachelor's degree (%) | 20 | 1.73 | 2 | 38.46 | -0.0215 | -0.647 | | |

† Values (from 200 permutations) are reported for all $P < 0.05$.

independent variables. To simplify the display, only bird species with a goodness of fit >0.1 are shown in the triplot. In addition to separate RDAs for each subset of environmental variables, we also decomposed the variance of the bird community that could be explained independently and jointly by each of the variable subsets using variance partitioning. This allowed us to examine the total variance explained by all three variable subsets, the variance that is unique to the socioeconomic variables, and the variance that is shared among the variables, while controlling for their confoundedness (Borcard et al. 1992).

To test if the native vegetation variables (number of shrubs and number of thin-leaf evergreen trees) predicted total native bird diversity at a site, we conducted linear regression analyses. Using a linear regression, we also tested whether residents' satisfaction with diversity or desire for diversity were predicted by actual native species richness. Since satisfaction could be influenced by overall increased environmental or bird knowledge (Boxall and McFarlane 1995), we tested the importance of covariates of the native bird diversity richness by including income and education level from the U.S. Census data in a multiple linear regression model. We checked for normality of the data and transformed when necessary. All analyses were conducted using R (R Development Core Team 2008) with the vegan package (Oksanen et al. 2009).

RESULTS

We detected 64 bird species during the study. Species richness of sites ranged from 12 to 34 (19 ± 4.5 species; mean \pm SD), and total bird abundance at sites ranged from 31 to 145 species (72.3 ± 27.99 species). We recorded six invasive species, 37 generalist species, and 21 desert species (Appendix A).

Habitat and landscape planting variables

Transects contained 1–17 yards each (7.9 ± 2.67 yards; mean \pm SD). Vegetation composition differed between the two dominant landscape designs (mesic and xeric; Table 1). Based on the 100-m transects of residential streets, xeric neighborhoods had on average three times as many shrubs as mesic neighborhoods (27.6 shrubs per xeric transect compared with 9.8 shrubs per mesic transect). Tree density and composition also differed; mesquite (*Prosopis* sp.), palo verde (*Parkinsonia* sp.), and other desert trees dominated xeric transects with an average of 8.9 trees per transect compared to 1.9 trees per mesic transect. Conifers (e.g., Afghan pine *Pinus eldarica*), monocots, (e.g., Mexican fan palms *Washingtonia robusta*), and citrus trees dominated mesic transects (5.9, 6.9, and 6.7 trees per mesic transect, respectively; 2, 5.8, and 4.5 trees per xeric transect, respectively). Transects were relatively homogeneous. In transects where at least 50% of the yards classified as a mesic ground cover (turf), 72% of the yards were mesic. In transects where at least 50% of the yards classified as a xeric ground cover (crushed gravel), 80% of the yards were xeric.

The ordinations

The bird community in Phoenix was disproportionately influenced by our three variable subsets. The habitat RDA explained 28.8% of the variation (constrained inertia), the urban gradient RDA explained 16.1% of the variation, and the socioeconomic RDA explained 22.1% of the variation. All three ordinations were significant: the proportion of variation in the bird community as explained by the habitat, urban gradient, and socioeconomic variables was greater than expected by chance (Monte Carlo permutation test/ANOVA,

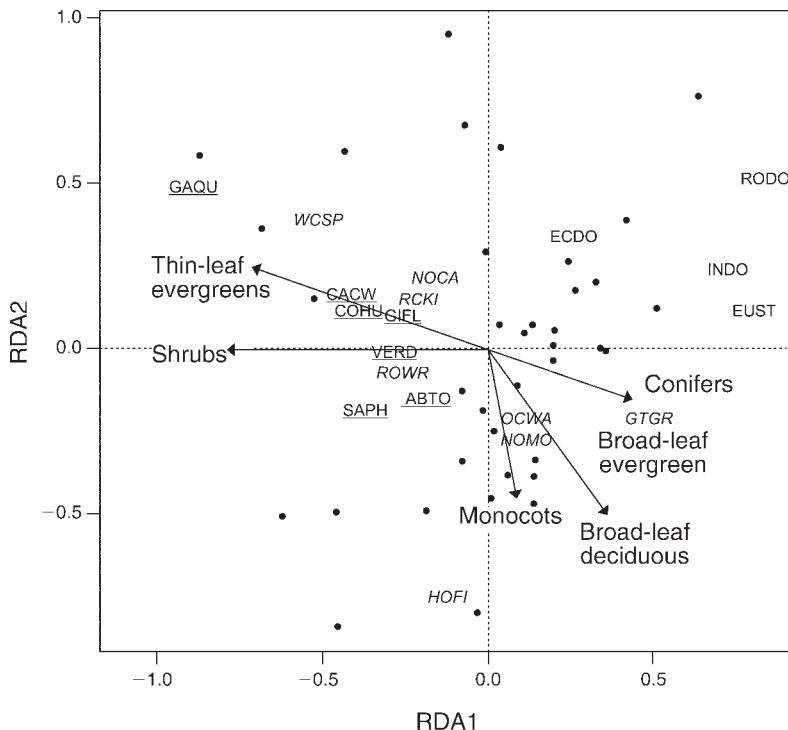


Fig. 2. Ordination diagram of the habitat redundancy analysis (RDA) of the bird community in Phoenix neighborhoods. Arrows represent the direction of change of the habitat measures (shown in boldface type). The length of the arrow indicates the variable's importance in explaining the urban bird community. Angles between variables indicate the correlation between the habitat measurements. Bird species locations relative to each other indicate their similarity in ordination space. Bird species locations relative to the habitat measurements indicate the habitat associations for that species. Dots represent sites. Underlined species are desert birds, italicized species are generalist birds, and plain-font species are invasive birds. The majority of the desert bird species clustered along the shrub and the thin-leaf evergreen environmental vector, indicating that desert bird species increased their abundances as the density of desert and drought-tolerant vegetation increased. Bird species abbreviations are Abert's Towhee (ABTO), Cactus Wren (CACW), Costa's Hummingbird (COHU), Eurasian Collared Dove (ECDO), European Starling (EUST), Gambel's Quail (GAQU), Gilded Flicker (GFL), Great-tailed Grackle (GTGR), House Finch (HOFI), Inca Dove (INDO), Northern Cardinal (NOCA), Northern Mockingbird (NOMO), Orange-crowned Warbler (OCWA), Rock Pigeon (RODO), Rock Wren (ROWR), Ruby-crowned Kinglet (RCKI), Say's Phoebe (SAPH), Verdin (VERD), and White-crowned Sparrow (WCSP).

$F_{6,32} = 2.14, P < 0.005$; $F_{3,35} = 2.24, P < 0.005$; and $F_{5,33} = 1.87, P = 0.01$, respectively). For each of the three ordinations, only the first axis was significant (ANOVA, $F_{6,32} = 5.58, P < 0.005$; $F_{3,35} = 4.66, P < 0.005$; and $F_{5,33} = 5.58, P < 0.005$, respectively), and therefore we interpreted only the first axes on all three triplots (McCune and Grace 2002). Based on the variance partitioning analysis, collectively the three variable subsets explained 48% of the variation in the bird abundance data, with each subset having similar explanatory proportions as the RDA. The shared variation between all three subsets was 13.2%, indicating that each subset provided unique information on the factors relating to the bird community patterns. The habitat variables shared ~7% of the variation with urban gradient measurements and the socioeconomic variables.

Our native/exotic classification emerged as a defining element for explaining the urban bird community for the habitat RDA, as shown along Axis 1 (Fig. 2). The majority of the desert bird community clustered along

the shrub and thin-leaf evergreen environmental vector, indicating that desert bird species increased their abundances as the density of desert and drought-tolerant vegetation increased. Invasive and generalist bird species were positively associated with neighborhoods with little or no native vegetation (Figs. 2, 5, Table 1). The socioeconomic ordination showed a strong ethnic/income/education gradient along Axis I. Invasive and generalist species increased their abundance in predominantly Hispanic neighborhoods where desert bird species were positively associated with higher-income and more educated neighborhoods. Lower-income and predominantly Hispanic neighborhoods had the least number of bird species at higher relative abundances, and none of these birds were desert species (Fig. 3, Table 1). The urban gradient ordination showed a strong urban-rural gradient along Axis I. Desert bird species increased their abundance as the distance to desert tracts decreased, while invasive species increased in abundances in older neighborhoods (Fig. 4, Table 1).

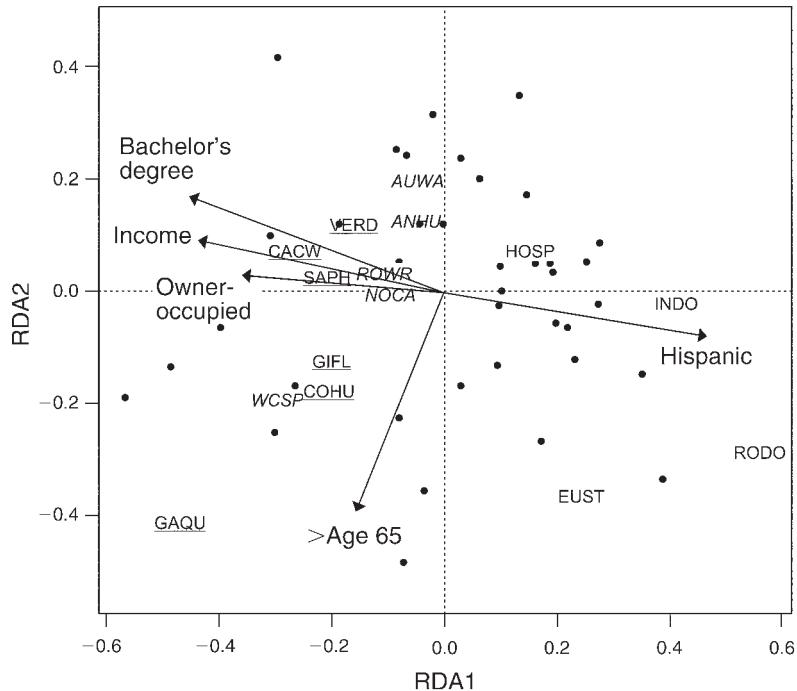


FIG. 3. Ordination diagram of the socioeconomic variables redundancy analysis (RDA) of the bird community in Phoenix neighborhoods. Arrows represent the direction of change of the habitat measures (shown in boldface type). The length of the arrow indicates the variable's importance in explaining the urban bird community. Angles between variables indicate the correlation between the socioeconomic measurements. Bird species locations relative to each other indicate their similarity in ordination space. Dots represent sites. Underlined species are desert birds, italicized species are generalist birds, and plain-font species are invasive birds. The majority of the desert bird species increased their abundances in higher-income and higher-educated neighborhoods and in neighborhoods with a high percentage of home ownership. Only invasive species increased their abundances in lower-income and Hispanic neighborhoods. Bird species abbreviations are Anna's Hummingbird (ANHU), Audubon's Warbler (AUWA), Cactus Wren (CACW), Costa's Hummingbird (COHU), European Starling (EUST), Gambel's Quail (GAQU), Gilded Flicker (GIFL), House Sparrow (HOSP), Inca Dove (INDO), Northern Cardinal (NOCA), Rock Pigeon (RODO), Rock Wren (ROWR), Say's Phoebe (SAPH), Verdin (VERD), and White-crowned Sparrow (WCSF).

Total native bird richness was positively correlated with thin-leaf evergreen trees and shrubs (linear regressions, $r^2 = 0.49$, $F_{1,37} = 35.80$, $P < 0.001$, and $r^2 = 0.42$, $F_{1,37} = 27.17$, $P < 0.001$, respectively), both of which are indicative of desert landscaping.

Social survey results (PASS)

Satisfaction with the existing variety of birds increased with actual bird diversity ($r^2 = 0.30$, $F_{1,37} = 15.76$, $P = 0.0003$; Fig. 6). Nearly twice as many respondents gave positive satisfaction ratings (93%) of bird richness in neighborhoods with high actual bird diversity as in neighborhoods with low diversity (47%). Respondent's ratings of their ideal variety of birds did not have a significant relationship with actual richness ($r^2 = 0.004$, $F_{1,37} = 0.16$, $P = 0.70$), though most rated it as having high or moderate desirability (81%). The multiple linear regression model for the existing variety of birds was also significant ($r^2 = 0.48$, $F_{3,35} = 10.63$, $P < 0.001$). Bird diversity and income were significant in the model while education level was not ($t = 2.42$, $P = 0.02$; $t = 2.83$, $P < 0.01$; $t = -0.64$, $P = 0.53$, respectively). The

multiple linear regression model of ideal variety of birds was not significant ($r^2 = 0.03$, $F_{3,35} = 0.32$, $P = 0.81$).

DISCUSSION

Residential yards, regardless of their spatial position along the urban-rural gradient have the potential to support and increase urban biodiversity when landscaped with native plants. By comparing the relative importance of local vegetation in residential yards with regional landscape features, our study found that the local habitat variables had twice the explanatory power relative to the regional landscape features to describe the patterns of the urban bird community. These results have important applications for urban planners and landscape designers at a variety of urban settings and locations and will help to identify opportunities for enhancing biodiversity at any place along an urban gradient. Our results support a growing body of literature on the importance of local habitat features (reviewed in Evans et al. 2009), but more importantly, our study is one of the first to provide a scientific basis for implementing the use of native plants to attract

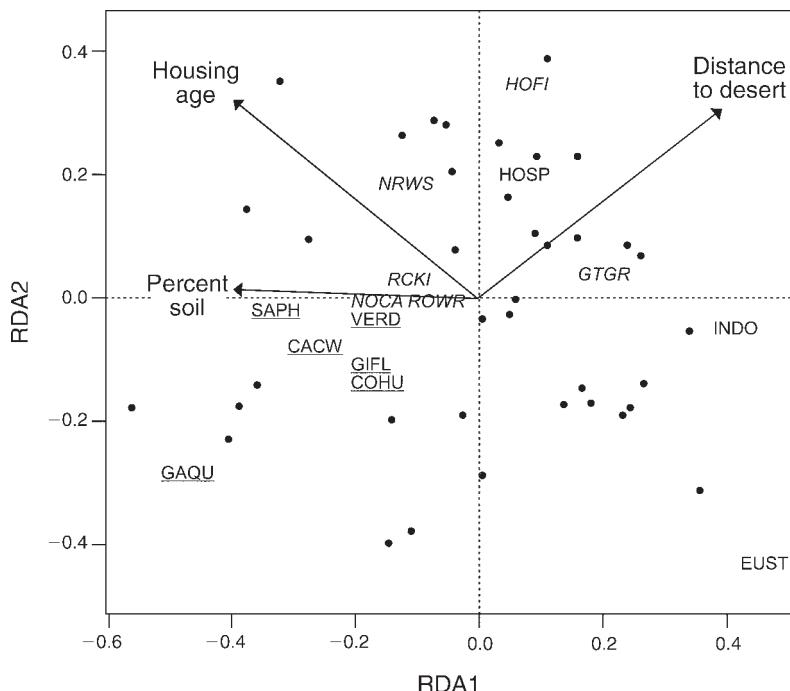


FIG. 4. Ordination diagram of the urban gradient measurements redundancy analysis (RDA) of the bird community in Phoenix neighborhoods. Arrows represent the direction of change of the urban gradient measures (shown in boldface type). The length of the arrow indicates the variable's importance in explaining the urban bird community. Angles between variables indicate the correlation between the urban gradient measurements. Bird species locations relative to each other indicate their similarity in ordination space. Bird species abbreviations relative to the urban gradient measurements indicate the variable associations for that species. Dots represent sites. Underlined species are desert birds, italicized species are generalist birds, and plain-font species are invasive birds. The majority of the desert bird species increased their abundances in newer neighborhoods and neighborhoods closer to desert patches. Bird species abbreviations are Cactus Wren (CACW), Costa's Hummingbird (COHU), European Starling (EUST), Gambel's Quail (GAQU), Gilded Flicker (GIFFL), Great-tailed Grackle (GTGR), House Finch (HOFI), House Sparrow (HOSP), Inca Dove (INDO), Northern Cardinal (NOCA), Northern Rough-winged Swallow (NRWS), Rock Wren (ROWR), Ruby-crowned Kinglet (RCKI), Say's Phoebe (SAPH), and Verdin (VERD).

native wildlife in residential yards (Goddard et al. 2010). Our study also highlighted the variation in access to nature whereby certain socioeconomic groups live in "biological poverty" (Turner et al. 2004).

Landscape plantings and the urban gradient

The results have immediate applications for existing residential yards and future developments. Our linear models demonstrated that about half of the desert bird community was detected when a 100-m transect contained at least 10 desert trees and approximately 20 shrubs (Fig. 5). This implies that even a small number of native plants can attract desert birds. Interestingly, the mean number of desert trees (8.9) and shrubs (27.6) per transect for xeric yards was very close to this predicted minimum. These recommendations can assist landscape designers and urban planners working in new neighborhood developments and working to retrofit existing neighborhoods to improve conditions for desert birds.

Although the urban gradient measurements performed poorly when compared with the habitat and socioeconomic variables, they hinted at important ecological features necessary for attracting desert birds

to arid cities. We found a mean distance of 3.8 km between the neighborhoods (point count location) and desert patches. This suggests that pockets of desert habitat exist throughout Phoenix and are not restricted to areas closer to the edge of the city. These desert patches might serve as population sources, allowing the desert bird community to disperse throughout Phoenix. However, our study addressed only distribution patterns and abundances and did not test for survival, reproductive success, or other fitness measurements. The urban gradient measurements described some of the physical components of the landscape and addressed factors that might hinder or assist with the colonization of desert birds within urban areas. By exploring the vegetation variation within the gradient, we found that the inclusion of native yard plantings might explain why native birds persist throughout the city.

Our data suggest that with increasing time since development, the likelihood of a neighborhood supporting an invasive bird community also increased (Fig. 4). Some studies have found that older neighborhoods have higher bird richness, attributed to the presence of mature vegetation (e.g., Munyenyembe et al. 1989, Palomino

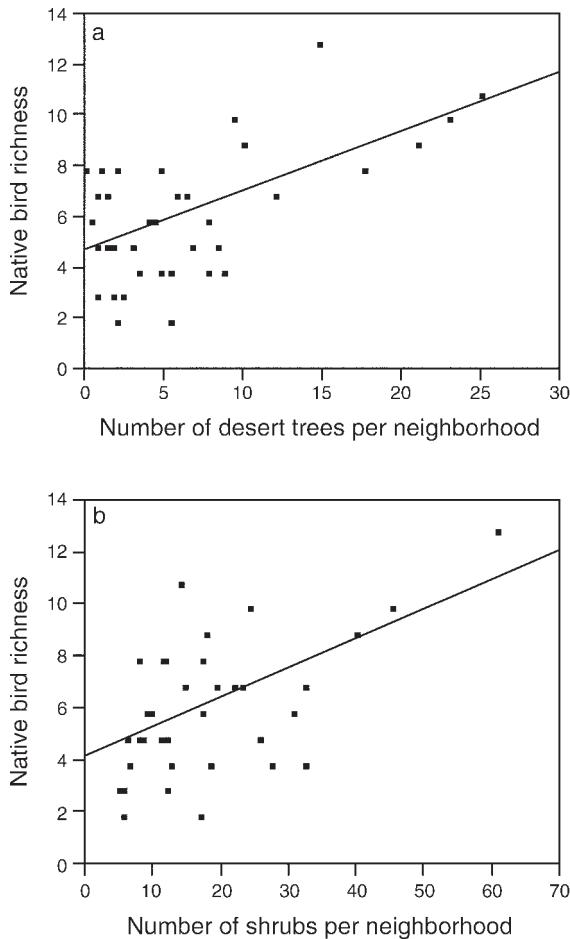


FIG. 5. The relationship between native bird species richness (number of native bird species per point count) and desert vegetation at 39 neighborhoods in Phoenix: (a) desert trees (thin-leaf evergreen trees; $r^2 = 0.49$, $F = 35.80$, $P < 0.001$), (b) shrubs ($r^2 = 0.42$, $F = 27.17$, $P < 0.001$).

and Carrascal 2005), while other studies found diversity decreased with housing age (e.g., Hepinstall et al. 2008, Loss et al. 2009). A post hoc analysis showed no significant relationship between housing age and bird richness in Phoenix (linear regression, $F = 0.43$, $P = 0.52$), but older neighborhoods did attract distinctly different bird communities (Fig. 4). These disparate findings likely reflect differences among cities in the relationship of housing age to geographical location, urban development history, and landscaping trends (Warren et al. 2010).

In Phoenix, changing landscaping practices over time may help explain the complex relationship of housing age to the bird communities. Before air conditioners, Phoenicians mitigated the extreme summer temperatures with mesic landscaping, characterized by large shade trees, turf, and flood irrigation. This landscape design created a cooling effect and greatly reduced temperatures in residential areas (Folkner 1958). Once air

conditioners became a common household commodity, the popularity of xeric landscaping designs grew, and urbanites embraced a more desertlike landscape with drought-tolerant trees, cacti, and shrubs and replaced the lawn with crushed gravel (McPherson and Haip 1989, Martin 2001, Larsen and Harlan 2006). Thus older neighborhoods are more likely to be mesicscaped than new ones, conditions likely to support a greater abundance of invasive bird species (Fig. 4).

Socioeconomics and bird communities

By including socioeconomic variables, we explored the patterns of human-wildlife interactions, specifically addressing how different socioeconomic groups indirectly associate with an urban bird community. Our socioeconomic redundancy analysis revealed strong environmental inequities; predominantly Hispanic and lower-income neighborhoods had few to no desert birds (Fig. 3). These results are in accord with previous findings from Phoenix and from Vancouver, British Columbia, Canada, where plant and bird diversity increased with socioeconomic status (Hope et al. 2003, Kinzig et al. 2005, Melles 2005, Walker et al. 2009). However, they differ from a study in Chicago, Illinois, USA, which found an inverse relationship between income and bird richness (Loss et al. 2009). Our study differs from these previous studies in its exclusive focus on residential yards, a difference that may account in part for the differences between patterns found in Phoenix and Chicago.

Additional mechanisms must be invoked to account for the unique information provided by the socioeconomic variables and their association with the bird communities. Some possible factors include bird feeding and urban noise. The presence of bird feeders have strong influences on residential yard bird communities and have been linked to socioeconomic factors (Lepczyk et al. 2004, Fuller et al. 2008; Lepczyk et

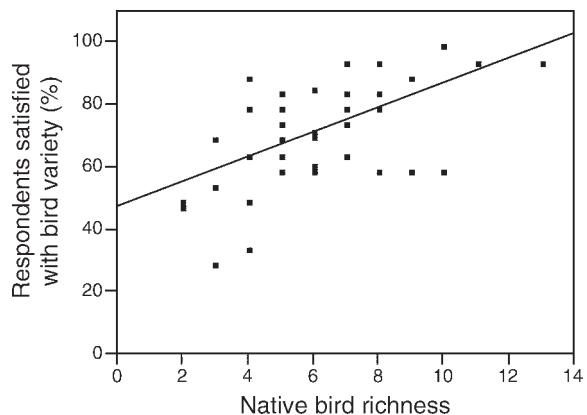


FIG. 6. The relationship between the percentage of respondents in a neighborhood satisfied with bird variety and the actual native bird richness at 39 neighborhoods in Phoenix ($r^2 = 0.30$, $F = 15.76$, $P = 0.0003$).

al., *in press*). Americans spend about \$30 billion per year on seed and feeders (U.S. Fish and Wildlife Service 2002). However, Lepczyk et al. (*in press*) did not find a significant relationship between income and the propensity to feed birds in a survey comparing residents in southeast Michigan, USA, and Phoenix. They did, however, find a relationship between the types of food provided and income level in Phoenix. Higher-income residents were more likely to have thistle and hummingbird feeders, perhaps due to the higher cost of these food sources. By contrast, the lower-income neighborhoods might be limited to one or two commercial food sources, and these feeding stations might provide resources for pest and exotic species (Daniels and Kirkpatrick 2006). This specialization of certain feeder foods and the economic costs might help explain higher levels of bird diversity in higher-income neighborhoods. Future studies that test how different bird feeder foods interrelate with the bird community will help disentangle these relationships. Urban and suburban areas are also characterized by having elevated noise levels; however, there is a great amount of variation within these areas (Warren et al. 2006). For example, areas closer to urban center and in lower-income neighborhoods tend to have higher noise levels (Warren et al. 2006). The elevated noise might be a limiting factor (i.e., the inability to communicate with conspecifics) for birds with lower frequencies or the inability to shift frequencies (Slabbekoorn and Peet 2003), though we did not test for this biological trait.

Our study identified which socioeconomic groups were experiencing subpar levels of biodiversity and also identified some specific habitat features for inclusion in neighborhood improvement activities. Planting more native vegetation could help improve native biodiversity in Hispanic and lower-income neighborhoods. When incorporating planting efforts in different socioeconomic neighborhoods, we must account for the variation within the human population. Landscaping choices are often influenced by socioeconomic and cultural factors such as landowner's ethnicity, education, and income (Kaplan and Talbot 1988, Kent 1993, Larsen and Harlan 2006) rather than biophysical determinants of soil, elevation, and climate (Whitney and Adams 1980, Walker et al. 2009). These differences help explain the interplay between socioeconomic factors and the vegetation in residential yards. For example, residents in higher-income neighborhoods might actively landscape according to their preferences and not be limited by economic constraints (Larsen and Harlan 2006). Some studies have suggested that residents in lower-income neighborhoods prefer a simpler, low-maintenance landscape, with fewer trees and shrubs (Seddon 1997, Kirkpatrick et al. 2007). These landscaping decisions yield a mosaic of different landscape designs across the city and help explain some of the variation in urban bird communities. Furthermore, the lower-income and ethnic neighborhoods have larger percentages of renters.

Because of the ephemeral nature of renters, they are less likely to invest in long-term landscape improvements at their current residence. These socioeconomic landscaping patterns represent a challenge for landscape planners whose goal is to incorporate native plantings in residential neighborhoods. Wildlife agencies and conservation organizations need to identify creative ways to educate urban residents on the importance of their landscaping decisions while being sensitive to cultural traditions and economic conditions.

Residents' perception of diversity

The strength of the relationship between bird species composition and socioeconomic variables raises another question. Do the residents in these neighborhoods notice the differences in biodiversity? Addressing these perceptions of biodiversity allowed us to investigate human-wildlife interactions at a finer scale. Results from the PASS study suggested that people noticed varying levels of bird diversity in their yards, as indicated by how their varying levels of satisfaction correlated with actual diversity. As a caveat to these results, the level of satisfaction with bird diversity may reflect the resident's overall satisfaction of their neighborhood. All the neighborhood satisfaction variables (e.g., positive interactions with neighbors, housing value, and proximity to nature) in the PASS study were positively correlated with each other (S. Harlan, *personal communication*), and with income level. Even so, our results suggested that neighborhoods that appeal to people also support higher biodiversity.

Implications

The discrepancies in biodiversity among neighborhoods are a serious concern for urban planners and conservation scientists because they could lead to an "extinction of experience" (Pyle 1978). As the biota in predominantly lower-income and (in our study) Hispanic neighborhoods become increasingly homogenized (McKinney 2006), urban dwellers may lose their sense of wonder and amazement for nature, primarily from lack of opportunities to experience native species in their yards (Pyle 1978, Turner et al. 2004, Miller 2005).

For many urbanites, their primary interactions with nature occur in their front and back yards (DeStefano and DeGraaf 2003). Providing opportunities for positive experiences with the natural world leads to an increased sensitivity to ecological issues, an ability to incorporate sound ecological initiatives into public policy, and ultimately the ability and desire to conserve urban biodiversity (Hough 1995, Savard et al. 2000, Rosenzweig 2003, Turner et al. 2004, Miller 2005). Attention to socioeconomic patterns as well as local habitat features, urbanization intensity, and human environmental preferences in describing studies and future plans is essential to more fully grasp the complexity of human-dominated ecosystems.

ACKNOWLEDGMENTS

We thank J. P. Smith and L. Stewart for field assistance, and S. Earl for logistics. Comments and suggestions by S. Harlan, S. Haire, and two anonymous reviewers greatly improved the manuscript. S. B. Lerman was supported by a Switzer Environmental Fellowship from the Robert and Patricia Switzer Foundation. This material is based upon work supported by the National Science Foundation under Grant No. DEB-0423704, Central Arizona-Phoenix Long-Term Ecological Research (CAP LTER). Any opinions, findings, and conclusions or recommendation expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation (NSF).

LITERATURE CITED

- Adams, C. C. 1935. The relation of general ecology to human ecology. *Ecology* 16:316–335.
- Beissinger, S. R., and D. R. Osborne. 1982. Effects of urbanization on avian community organization. *Condor* 84:75–83.
- Blair, R. B. 1996. Land use and avian species diversity along an urban gradient. *Ecological Applications* 6:506–519.
- Borcard, D., P. Legendre, and P. Drapeau. 1992. Partialling out the spatial component of ecological variation. *Ecology* 73:1045–1055.
- Boxall, P. C., and B. L. McFarlane. 1995. Analysis of discrete, dependent variables in human dimensions research: participation in residential wildlife appreciation. *Wildlife Society Bulletin* 23:283–289.
- Burghardt, K. T., D. W. Tallamy, and W. G. Shriver. 2009. Impact of native plants on bird and butterfly biodiversity in suburban landscapes. *Conservation Biology* 23:219–224.
- Cannon, A. 1999. The significance of private gardens for bird conservation. *Bird Conservation International* 9:287–297.
- Chace, J. F., and J. J. Walsh. 2006. Urban effects on native avifauna: a review. *Landscape and Urban Planning* 74:46–69.
- Chamberlain, D. E., A. R. Cannon, and M. P. Toms. 2004. Associations of garden birds with gradients in garden habitat and local habitat. *Ecography* 27:589–600.
- Croci, S., A. Butet, and P. Clergeau. 2008. Does urbanization filter birds on the basis of their biological traits? *Condor* 110:223–240.
- Daniels, G. D., and J. B. Kirkpatrick. 2006. Does variation in garden characteristics influence the conservation of birds in suburbia? *Biological Conservation* 133:326–335.
- DeStefano, S., and R. M. DeGraaf. 2003. Exploring the ecology of suburban wildlife. *Frontiers in Ecology and the Environment* 1:95–101.
- Donnelly, R., and J. M. Marzluff. 2004. Importance of reserve size and landscape context to urban bird conservation. *Conservation Biology* 18:733–745.
- Emlen, J. T. 1974. Urban bird community in Tucson, Arizona: derivation, structure, regulation. *Condor* 76:184–197.
- ERDAS. 2006. Imagine software. Version 9.1. ERDAS, Atlanta, Georgia, USA.
- ESRI. 2006. ArcMap 9.2. ESRI, Redlands, California, USA.
- Evans, K. L., S. E. Newson, and K. J. Gaston. 2009. Habitat influences on urban avian assemblages. *Ibis* 151:19–39.
- Folkner, J. S. 1958. *Landscape Arizona homes*. Tucson, Arizona, USA. University of Arizona, Agriculture Experimental Station.
- Fuller, R. A., K. N. Irvine, P. Devine-Wright, P. H. Warren, and K. J. Gaston. 2007. Psychological benefits of greenspace increase with biodiversity. *Biology Letters* 3:390–394.
- Fuller, R. A., P. H. Warren, P. R. Armsworth, O. Barbosa, and K. J. Gaston. 2008. Garden bird feeding predicts the structure of urban avian assemblages. *Diversity and Distributions* 14:131–137.
- Gaston, K. J., P. H. Warren, K. Thompson, and R. M. Smith. 2005. Urban domestic gardens (IV): the extent of the resource and its associated features. *Biodiversity and Conservation* 14:3327–3349.
- Germaine, S. S., S. S. Rosenstock, R. E. Schweinsburg, and W. S. Richardson. 1998. Relationships among breeding birds, habitat, and residential development in Greater Tucson, Arizona. *Ecological Applications* 8:680–691.
- Goddard, M. A., A. J. Dougill, and T. G. Benton. 2010. Scaling up from gardens: biodiversity conservation in urban environments. *Trends in Ecology and Evolution* 25:90–98.
- Grimm, N. B., and C. L. Redman. 2004. Approaches to the study of urban ecosystems: the case of central Arizona-Phoenix. *Urban Ecosystems* 7:199–213.
- Grove, J. M., A. R. Troy, J. P. M. O'Neil-Dunne, W. R. Burch, M. L. Cadenasso, and S. T. A. Pickett. 2006. Characterization of households and its implications for the vegetation of urban ecosystems. *Ecosystems* 9:578–597.
- Harlan, S. L., S. T. Yabiku, L. Larsen, and A. J. Brazel. 2009. Household water consumption in an arid city: affluence, affordability, and attitudes. *Society and Natural Resources* 22:691–709.
- Hepinstall, J., M. Alberti, and J. Marzluff. 2008. Predicting land cover change and avian community responses in rapidly urbanizing environments. *Landscape Ecology* 23:1257–1276.
- Hope, A. C. A. 1968. A simplified Monte Carlo significance test procedure. *Journal of the Royal Statistical Society Series B* 30:582–598.
- Hope, D., C. Gries, W. X. Zhu, W. F. Fagan, C. L. Redman, N. B. Grimm, A. L. Nelson, C. Martin, and A. Kinzig. 2003. Socioeconomics drive urban plant diversity. *Proceedings of the National Academy of Sciences USA* 100:8788–8792.
- Horowitz, P., M. Lindsay, and M. O'Connor. 2001. Biodiversity, endemism, sense of place, and public health: interrelationships for Australian inland aquatic systems. *Ecosystem Health* 7:253–265.
- Hough, M. 1995. *Cities and natural process*. Routledge, London, UK.
- Jenerette, G. D., S. L. Harlan, A. Brazel, N. Jones, L. Larsen, and W. L. Stefanov. 2007. Regional relationships between surface temperature, vegetation, and human settlement in a rapidly urbanizing ecosystem. *Landscape Ecology* 22:353–365.
- Kaplan, R., and J. F. Talbot. 1988. Ethnicity and preference for natural settings: a review and recent findings. *Landscape and Urban Planning* 15:107–117.
- Kent, R. L. 1993. Attributes, features and reasons for enjoyment of scenic routes: a comparison of experts, residents and citizens. *Landscape Research* 18:92–102.
- Kinzig, A., P. S. Warren, C. Martin, D. Hope, and M. Katti. 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. *Ecology and Society* 10:23. (www.ecologyandsociety.org/vol10/iss1/art23/)
- Kirkpatrick, J. B., G. D. Daniels, and T. Zagorski. 2007. Explaining variation in front gardens between suburbs of Hobart, Tasmania, Australia. *Landscape and Urban Planning* 79:314–322.
- Larsen, L., and S. L. Harlan. 2006. Desert dreamscapes: residential landscape preference and behavior. *Landscape and Urban Planning* 78:85–100.
- Legendre, P., and E. D. Gallagher. 2001. Ecologically meaningful transformations for ordination of species data. *Oecologia* 129:271–280.
- Lepczyk, C. A., A. G. Mertig, and J. G. Liu. 2004. Assessing landowner activities related to birds across rural-to-urban landscapes. *Environmental Management* 33:110–125.
- Lepczyk, C. A., P. S. Warren, L. Machabee, A. P. Kinzig, and A. G. Mertig. *In press*. Who feeds the birds? An urban comparison between Phoenix, Arizona and Southeastern Michigan. *Studies in Avian Biology*.

- Logan, J., and H. Molotch. 1987. *Urban fortunes: the urban economy of place*. University of California Press, Berkeley, California, USA.
- Loss, S. R., M. O. Ruiz, and J. D. Brawn. 2009. Relationships between avian diversity, neighborhood age, income, and environmental characteristics of an urban landscape. *Biological Conservation* 142:2578–2585.
- Martin, C. A. 2001. Landscape water use in Phoenix, Arizona. *Desert Plants* 17:26–31.
- Martin, C. A., K. A. Peterson, and L. B. Stabler. 2003. Residential landscaping in Phoenix, Arizona, U.S.: practices and preferences relative to covenants, codes, and restrictions. *Journal of Arboriculture* 29:9–17.
- Martin, C. A., P. S. Warren, and A. P. Kinzig. 2004. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, AZ. *Landscape and Urban Planning* 69:355–368.
- Marzluff, J. M. 2001. Worldwide urbanization and its effects on birds. Pages 19–38 in J. M. Marzluff, R. Bowman, and R. Donnelly, editors. *Avian ecology and conservation in an urbanizing world*. Kluwer, Boston, Massachusetts, USA.
- McCune, B., and J. B. Grace. 2002. *Analysis of ecological communities*. MjM Software Design, Glenden Beach, Oregon, USA.
- McGarigal, K., S. Cushman, and S. Stafford. 2000. *Multivariate statistics for wildlife and ecology research*. Springer, New York, New York, USA.
- McKinney, M. L. 2006. Urbanization as a major cause of biotic homogenization. *Biological Conservation* 127:247–260.
- McPherson, E. G., and R. A. Haip. 1989. Emerging desert landscape in Tucson. *Geographical Review* 79:435–449.
- Melles, S. 2005. Urban bird diversity as an indicator of human social diversity and economic inequality in Vancouver, British Columbia. *Urban Habitats* 3:25–48.
- Miller, J. R. 2005. Biodiversity conservation and the extinction of experience. *Trends in Ecology and Evolution* 20:430–434.
- Mills, G. S., J. B. Dunning, and J. M. Bates. 1989. Effects of urbanization on breeding bird community structure in southwestern desert habitats. *Condor* 91:416–428.
- Munyenembe, F., J. Harris, J. Hone, and H. Nix. 1989. Determinants of bird populations in an urban area. *Australian Journal of Ecology* 14:549–557.
- Oksanen, J., R. Kindt, P. Legendre, B. O'Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, and H. Wagner. 2009. *vegan: community ecology package*. R package version 1.15-4. (<http://CRAN.R-project.org/package=vegan>)
- Palomino, D., and L. M. Carrascal. 2005. Urban influence on birds at a regional scale: a case study with the avifauna of northern Madrid province. *Landscape and Urban Planning* 77:276–290.
- Pyle, R. M. 1978. The extinction of experience. *Horticulture* 56:64–67.
- R Development Core Team. 2008. *R: a language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. (<http://www.R-project.org>)
- Ralph, C., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante. 1993. *Handbook of field methods for monitoring landbirds*. General Technical Report PSW-GTR-144. Albany, California, USA.
- Reichard, S. H., and P. White. 2001. Horticulture as a pathway of invasive plant introductions in the United States. *BioScience* 51:103–113.
- Rosenzweig, M. L. 2003. *Win-win ecology: how the Earth's species can survive in the midst of human enterprise*. Oxford University Press, Oxford, UK.
- Rudd, H., J. Vala, and V. Schaefer. 2002. Importance of backyard habitat in a comprehensive biodiversity conservation strategy: a connectivity analysis of urban green spaces. *Restoration Ecology* 10:368–375.
- Savard, J. P. L., P. Clergeau, and G. Mennechez. 2000. Biodiversity concepts and urban ecosystems. *Landscape and Urban Planning* 48:131–142.
- Seddon, G. 1997. *Landprints: reflections on place and landscape*. Cambridge University Press, Cambridge, UK.
- Shochat, E., P. S. Warren, S. H. Faeth, N. E. McIntyre, and D. Hope. 2006. From patterns to emerging processes in mechanistic urban ecology. *Trends in Ecology and Evolution* 21:186–191.
- Slabbekoorn, H., and M. Peet. 2003. Birds sing at a higher pitch in urban noise: Great Tits hit the high notes to ensure that their mating calls are heard above the city's din. *Nature* 424:267–267.
- Smith, R. M., K. J. Gaston, P. H. Warren, and K. Thompson. 2005. Urban domestic gardens (V): relationships between landcover composition, housing and landscape. *Landscape Ecology* 20:235–253.
- ter Braak, C. J. F. 1986. Canonical Correspondence Analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67:1167–1179.
- Troy, A. R., J. M. Grove, J. P. O'Neil-Dunne, S. T. Pickett, and M. L. Cadenasso. 2007. Predicting opportunities for greening and patterns of vegetation on private urban lands. *Environmental Management* 40:394–412.
- Turner, W. R., T. Nakamura, and M. Dinetti. 2004. Global urbanization and the separation of humans from nature. *BioScience* 54:585–590.
- United Nations Population Fund. 2007. *UNFPA state of world population 2007: unleashing the potential of urban growth*. United Nations Population Fund, New York, New York, USA.
- U.S. Census Bureau. *American factfinder: 2000. Census of population and housing, summary file*. (<http://factfinder.census.gov>)
- U.S. Fish and Wildlife Service. 2002. *2001 National Survey of fishing, hunting, and wildlife-associated recreation*. U.S. Department of the Interior, Washington, D.C., USA. (<http://www.census.gov/prod/2002pubs/FHW01.pdf>)
- Walker, J. S., N. B. Grimm, J. M. Briggs, C. Gries, and L. Dugan. 2009. Effects of urbanization on plant species diversity in central Arizona. *Frontiers in Ecology and the Environment* 7:465–470.
- Warren, P., M. Katti, M. Ermann, and A. Brazel. 2006. Urban bioacoustics: it's not just noise. *Animal Behaviour* 71:491–502.
- Warren, P. S., S. Harlan, C. Boone, S. B. Lerman, E. Shochat, and A. P. Kinzig. 2010. Urban ecology and social organization. Pages 172–201 in K. Gaston, editor. *Urban ecology*. Ecological Reviews series. Cambridge University Press, Cambridge, UK.
- Warren, P. S., S. B. Lerman, and N. D. Charney. 2008. Plants of a feather: spatial autocorrelation of gardening practices in suburban neighborhoods. *Biological Conservation* 141:3–4.
- Whitney, G. G., and S. D. Adams. 1980. Man as a maker of new plant-communities. *Journal of Applied Ecology* 17:431–448.

APPENDIX

Relative abundance of all bird species recorded in 39 Phoenix, Arizona, USA, neighborhoods (*Ecological Archives* A021-061-A1).