Decadal declines in bird abundance and diversity in urban riparian zones

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Abstract

Urbanization is frequently cited as a major driver of species losses worldwide; however, most studies in urban areas use a space-for-time substitution approach to document effects of urbanization through time. Ultimately, understanding the effects of urbanization on biodiversity requires long-term datasets. We examined long-term changes in bird assemblages at 12 riparian sites in the greater Phoenix metropolitan area and nearby Sonoran Desert region, featuring a range of human modifications and levels of water flow. Riparian areas in arid cities represent a key habitat type that is sensitive to human modification and supports high levels of species diversity. We used long-term data to: (1) explore variation in bird communities as a function of water permanence and degree of human-modification; (2) identify which environmental variables best describe differences found across riparian site types; and (3) assess how riparian bird communities, abundance, and species richness have changed through time. Engineered riparian sites supported more broadly distributed generalists; whereas, natural riparian sites supported more specialists. Sites with perennial flows had more vegetation and water compared to ephemeral sites and engineered sites had more impervious surface compared to natural sites. In nearly all comparisons, bird species richness, diversity, and abundance declined across riparian types during the period of study, even for common species. Bird communities in natural settings have changed more than communities at engineered sites. Overall, the riparian bird community is shifting toward urban dwelling, resident species that are characteristic of riparian sites with less water and more impervious surface.

1. Introduction

Worldwide, urban areas are expanding and are among the most rapidly changing landscapes. Urban areas modify wildlife habitat by replacing native vegetation cover with structures, roads, and other impervious surfaces (Czech, Krausman, & Devers, 2000) among many other effects (Pickett, Cadenasso, Grove, Boone, Groffman, et al., 2011). Bird species density (the number of species/area) in cities is reduced relative to surrounding regions, and appears to be highly sensitive to changes in land cover (Aronson, La Sorte, Nilon, Katti, Goddard, et al., 2014). However, most urbanization studies use a space-for-time substitution approach to document effects of urbanization through time (Pickett et al., 2011). Understanding effects of urbanization on biodiversity requires long-term datasets, which document temporal changes in species composition and species gains or losses (Magurran, Baillie, Buckland, Dick, Elston, et al., 2010; Strohbach, Hrycyna, & Warren, 2014).

Although cities are designed primarily for the benefit of humans, many species of wildlife persist and thrive in urban environments (Aronson et al., 2014; Marzluff, 2001; McKinney, 2002; Pickett et al., 2011). Many large cities occur along waterways, and can alter stream hydrology and watershed infiltration because of impervious surfaces (Paul & Meyer, 2001). However, a more basic challenge in arid ecosystems is to provide sufficient water to maintain riparian ecosystems. In arid cities, perennial water from novel urban sources, such as storm drains, can support riparian areas with diverse plant and bird communities (Bateman, Stromberg, Banville, Makings, Scott, et al., 2015). Compared to other ecosystems, riparian areas support some of the highest bird diversities (Knopf & Samson, 1994), but can also be habitats that are highly sensitive to modification (Naiman, Decamps, & Pollock, 1993). Therefore, there

is a growing need to identify sustainable mechanisms to restore and maintain urban riparian ecosystems and the services, such as habitat, they provide (Bernhardt & Palmer, 2007).

During the last century, the greater Phoenix metropolitan area in central Arizona has had one of the fastest growing populations in the United States (Hobbs & Stoops, 2002). In this region, a system of channels and canals transport water from reservoirs on the Verde, Salt, and Colorado Rivers (Gober, Wentz, Lant, Tschudi, & Kirkwood, 2011) to support a large urban population of 4 million in Maricopa County (U.S. Census Bureau, 2015). Employing datasets available from the Central Arizona–Phoenix Long-Term Ecological Research program (<https://caplter.asu.edu>), we examined the effects of urbanization on riparian habitats and bird communities in Phoenix and the surrounding Sonoran Desert region. The aims of our study were to: (1) explore variation in bird species richness, abundance, and community composition as a function of water permanence and degree of human-modification; (2) identify which environmental variables measured at different scales (site- and landscape-level) best describe differences in habitat characteristics found across riparian site types; and (3) examine the temporal patterns of avian abundance, species richness, and diversity across riparian site types.

2. Methods

2.1. Study area

Our research was conducted within the study area of the Central Arizona–Phoenix Long-Term Ecological Research program (hereafter CAP LTER), which encompasses the greater Phoenix metropolitan area and surrounding Sonoran Desert (hereafter Phoenix; Fig. 1). CAP LTER established two to four study sites in each of four riparian habitat types: (1) ephemeral-engineered (n=4); (2) ephemeral-natural (n=2); (3) perennial-engineered (n=3); and (4)

perennial-natural (n=3). CAP LTER defined types as ephemeral versus perennial based on the permanence of water. Types were also classified as engineered or natural defined by the degree of human-modification, which is more of a continuum rather than a dichotomy. Specifically, the ephemeral-engineered sites included a 200-m square retention basin surrounded by neighborhoods, two unlined earthen flood control channels surrounded by neighborhoods and golf courses, and one artificial water catchment surrounded by desert. The ephemeral-natural sites were along intermittent rivers surrounded by desert and some low density residential areas. The perennial-engineered sites included a landscaped riparian preserve, a constructed wetland, and a water retention area along the Salt River. These sites were surrounded by urban or agricultural areas. The perennial-natural sites were located along perennial river reaches and were surrounded by desert. Sites ranged between 295 and 683 m in elevation.

2.2. Bird surveys

Following Bibby, Burgess, Hill, and Mustoe (2000), CAP LTER used point count surveys with a 40-m fixed-radius where a trained observer recorded all birds seen and heard. At each point, the observer remained quiet for five minutes, then recorded birds for 15 minutes. Observers identified species based on Sibley (2000), and classified species according to Pyle and DeSante (2013). Birds detected beyond the 40-m truncation distance or that flew over the point were not counted, except for wide-ranging and foraging species (i.e. waterfowl, shorebirds, birds of prey, nighthawks, Greater Roadrunner, *Geococcyx californianus*; Belted Kingfisher, *Megasceryle alcyon*; and Loggerhead Shrike, *Lanius ludovicianus*). Surveys were conducted under similar environmental conditions and were completed within four hours of sunrise. From 2001 to 2013 (surveys were not conducted in 2003), three observers visited each point twice

annually, once during winter (end of December to mid-February) and once during spring (end of March to mid-May).

2.3. Vegetation and environmental variables

We collected eight site-level (within a 40-m radius around the point) and four landscape-level (within a 1-km radius around the point) environmental variables during spring 2013. Site-level variables included percent cover for marsh, water, impervious surface (i.e., pavement, structures, etc.), and bare ground. We used slightly modified Daubenmire (1959) cover classes (i.e., cover classes: none, 0-1%, 1-5%, 5-25%, 25-50%, 50-75%, 75-95%, >95%) to estimate percent cover for each category within a 40-m radius. We quantified vegetation at the site-level by selecting 10 random points stratified to represent all vegetation types present (i.e., riparian, Sonoran Desert, marsh, etc.). Points were at least 10 meters apart and none of the points were located in open water bodies or on roads. We recorded the proportion of random points where vegetation was present at three height classes (low, below 0.6 m; medium, 0.6–1.5 m; and high, above 1.5 m). We recorded percent canopy cover in four cardinal directions using a concave densiometer, averaged the four readings per point, then averaged over the 10 points. At the landscape level, we used ArcGIS 10.2 to quantify four land cover categories (i.e., impervious surface, bare ground, water, and vegetation) around each sampling site (1-km radius). Land cover categories were included in a land-cover classification dataset provided by CAP LTER, which was generated from 2010 National Agriculture Imagery Program (NAIP) imagery using methods detailed by Li, Myint, Zhang, Galletti, Zhang, et al. (2014).

2.4. Data analyses

To compare bird abundance and species richness across riparian habitat types through time, we used Bayesian modeling since we had an unbalanced design. We generated two Bayesian models (one for abundance and one for species richness) with Markov Chain Monte Carlo (MCMC) using package rjags (Plummer, 2014) for program R stats version 3.2.1 (R Core Team, 2013). The models followed a Poisson distribution (since data are univariate discrete numbers) with a log link function. As input, we used data from all three observers for each year and season. We used time as a covariate, and included a random effect for sites. We also included a novice observer effect to our models, since observers tend to have lower than expected count in the first year of conducting bird surveys (Kendall, Peterjohn, & Sauer, 1996). To compare how riparian type and season differ, we allowed parameters to vary by riparian type and season. We assigned non-informative priors with a normal distribution to parameters and novice observer effect. Since we had a small number of sites, for the site random effect, we assigned a zero-centered distribution to the hierarchical prior and used a folded-Cauchy distribution prior for its hyperparameter (precision). To be able to interpret intercepts and random effect, we employed a post-sweeping method to compute identifiable intercepts and random effect. For both models, we generated three independent MCMC chains and used Gelman-Rubin diagnostic to evaluate chains convergence. To generate the posterior distribution, we discarded the first 5,000 iterations to allow chains to converge, thinned by 25 to remove autocorrelation, and generated 1,000 sampled values per chain. To test model fit, we plotted replicated data against observed data.

To elucidate patterns in bird community structure, we used unconstrained ordinations, specifically non-metric multidimensional scaling (NMDS; Clarke, 1993) with Bray-Curtis distance, with square root and Wisconsin transformations, using program R stats version 3.1.1

with the Vegan package (Oksanen, Blanchet, Kindt, Legendre, Minchin, et al., 2013). We defined seasonal annual bird abundance per site as the maximum number of each species recorded among three visits. We excluded species with less than five total individuals observed during the 12 years, excluded species occurring only at one site, and removed unidentified observations. Some bird species with low occurrences, that otherwise would be excluded, were combined into the following feeding guilds: accipiters, falcons, fish eating raptors, terrestrial raptors, cormorants, nighthawks, sandpipers, yellowlegs, and dowitchers. We computed dispersion ellipses (based on standard deviation of weighted averages) to show separation of riparian types in species space. To identify differences in bird assemblages across riparian types, we generated ellipses for each type. To assess overall temporal change in community structure and allow smoothing of short-term fluctuations, we combined all sites into 3-year moving averages and generated ellipses around each temporal period (i.e., period 1 is the 3-year average for years 2001, 2002, 2004; period 10 is the 3-year average for years 2011-2013).

To assess temporal change in bird diversity per riparian type, we computed diversity profiles (Rényi's index family; Tóthmérész, 1995) using program R stats version 3.1.1 with Vegan package (Oksanen et al., 2013). We compared profiles for early (2001, 2002, 2004) and recent time frames (2011-2013).

To determine which environmental variables described habitat differences across riparian types, we used a permutation procedure to fit environmental variables onto spring bird ordination of recent years (2011-2013). Because site-level variables were collected in spring 2013, and landscape-level variables were based on remote-sensed images from 2010, we used only bird

data from spring of 2011, 2012, and 2013 as input to generate the NMDS. Significant values of environmental vectors revealed which variables characterized each riparian type.

3. Results

3.1. Bird abundance, richness, seasonality, and community composition

Bird community parameters varied seasonally and across riparian types. At perennial site types, we found greater abundances in winter than in spring (Table 1; Fig. 2). Within each season, bird abundance and species richness were higher at perennial sites compared to ephemeral sites (Table 1; Fig. 2; Appendix A). Bird abundance was highest at perennial-engineered sites during both seasons.

We also observed seasonal differences in riparian bird assemblages, with spring and winter bird communities composed of different migratory species (Appendix B, top panel). We interpreted a 3-dimensional solution for spring (NMDS stress = 19.9%, linear fit $R^2 = 71.3$), with the third axis depicting seasonal differences in migrants. Species present in winter included migratory waterfowl (i.e., Gadwall, *Anas strepera*; Common Merganser, *Mergus merganser*; and American Wigeon, *Anas americana*) and marsh birds (i.e., Wilson's Snipe, *Gallinago delicata*). Species common during spring included migratory riparian passerines (i.e., Yellow Warbler, *Setophaga petechia*; Lucy's Warbler, *Oreothlypis luciae*; Wilson's Warbler, *Cardellina pusilla*; and Bell's Vireo, *Vireo bellii*), doves (i.e., White-winged Dove, *Zenaida asiatica*), and hummingbirds (i.e., Black-chinned Hummingbird, *Archilochus alexandri*).

The four riparian types supported different bird community compositions (Appendix B, lower panels). The ordination for spring (NMDS stress = 18.1%, linear fit $R^2 = 77.1$) and

ordination for winter (NMDS stress = 18.7%, linear fit $R^2 = 74.2$) revealed 3-axis solutions. For both ordinations, Axis 1 depicted differences in bird community structure based on water presence (i.e., perennial or ephemeral); whereas, Axis 2 depicted differences based on degree of human-modification (i.e., natural or ephemeral). Engineered sites supported more broadly distributed generalists, such as Great-tailed Grackle (*Quiscalus mexicanus*), House Sparrow (*Passer domesticus*), Yellow-rumped Warbler (*Setophaga coronata*), Mourning Dove (*Zenaida macroura*), and European Starling (*Sturnus vulgaris*). Natural sites supported more specialist species, such as Northern Cardinal (*Cardinalis cardinalis*), Bewick's Wren (*Thryomanes bewickii*), and Black-throated Sparrow (*Amphispiza bilineata*). Sites with perennial water had high numbers of birds associated with water such as waterfowl, shorebirds, Black Phoebe (*Sayornis nigricans*), and Song Sparrow (*Melospiza melodia*); whereas, ephemeral sites supported Sonoran Desert species such as Gambel's Quail (*Callipepla gambelii*), and Curved-billed Thrasher (*Toxostoma curvirostre*).

3.2 Temporal shifts in bird community

We observed declining trends in abundance (Table 1) and species richness (Appendix A) during both spring and winter. Of the species with the most declines in abundance over time, 70% were passerine or songbirds (Appendix C). Most species in decline were present during both winter and spring surveys.

Declining trends in bird abundance and species richness occurred across all riparian types, with one exception: the perennial-engineered sites during spring had a slight increase in bird abundance across time (Table 1). The greatest declines (over 50%) in abundance and richness over the 12 year period occurred in natural sites. For both seasons, abundance and

species richness decreased annually at a greater rate in natural sites (6% to 7% declines) compared to engineered sites (1% to 3.5% declines). During spring, abundance at ephemeral sites decreased annually (around 6% decline) at a greater rate than perennial sites (2.5% decline); whereas, ephemeral and perennial sites decreased similarly during winter (4% to 5% declines). During both seasons, species richness at ephemeral sites decreased at similar annual rates (over 5% declines) compared to perennial sites (over 4% declines).

We observed temporal shifts in the composition of the riparian bird community for both seasons (Fig. 3). We interpreted a 3-dimensional solution for spring (NMDS stress = 13%, linear fit $R^2 = 88.4$) and 3-dimensional solution for winter (NMDS stress = 12.9%, linear fit $R^2 = 88.3$). As depicted by the trajectory of ellipses (representing the core of the bird community per temporal period), ordinations showed that riparian bird communities shifted toward assemblages found at ephemeral-engineered sites during both seasons.

Diversity profiles (Appendix D) indicated the riparian bird community has become less diverse through time across riparian types and seasons. We were unable to compare diversity profiles of early and recent time frames at perennial-natural sites in winter because their profiles did not rank consistently (illustrated by intersecting lines), thus not allowing comparisons.

3.3. Habitat characteristics of riparian types

We tested the fit of 12 environmental variables (Appendix E) onto the ordination for spring birds during recent years (3-axis solution, NMDS stress = 14.2%, linear fit $R^2 = 85.2$). We identified four site-level and four landscape-level variables that described differences in habitat characteristics among riparian types (Fig. 4). At the landscape-level, sites with perennial flows had more vegetation and water cover compared to ephemeral sites. Ephemeral-engineered sites

had the greatest amount of impervious surface; whereas, ephemeral-natural sites had the greatest amount of bare ground. At the site-level, perennial types had more water, canopy cover, and marsh compared to ephemeral sites. Among the perennial types, natural sites had a greater proportion of tall vegetation and dense canopy cover compared to engineered sites.

4. Discussion

Our study provides one of the very few assessments of decadal changes in urban bird communities (for global bird declines observed via long-term data see: Julliard, Jiguet, & Couvet, 2004; Clavel, Julliard, & Devictor, 2011). In riparian zones of the greater Phoenix metropolitan area and surrounding Sonoran Desert region, we documented declines in both abundance and species richness, with declines exceeding 50% at natural sites over a 12-year monitoring period (Table 1). Bird communities in Phoenix riparian sites have shifted toward assemblages dominated by fewer, more abundant and more typical ‘urban’ species (Fig. 3). However, even common, broadly distributed species also showed declines. Some of the species we observed are declining regionally or nationally. Thus, potential explanations for these shifts may include region-wide processes like drought or climate change. Alternatively, local land cover changes, like urban expansion and urban intensification may contribute to species losses via a variety of mechanisms including habitat loss and habitat degradation. We examine evidence for each of these explanations and discuss implications for safeguarding or enhancing riparian species diversity in cities.

4.1. Declines in bird community parameters during the last decade

One of the strengths of our study is the use of temporal rather than solely spatial comparisons. Although, we can compare which riparian types had the greatest abundance and

richness, only temporal analyses allowed us to document that bird species richness dwindled by more than 2-8% per year. The benefit of a long-term study is to document individual fluctuations and trends of species in a community (Picket et al., 2011).

Riparian bird diversity in Phoenix has declined due to decreases in both evenness and species richness. This decline suggests that the bird community has shifted toward an assemblage dominated by fewer more abundant species, a shift commonly found in other studies along spatial urbanization gradients (Melles, Glenn, & Martin, 2003; Shochat, Lerman, Anderies, Warren, Faeth, et al., 2010). This decrease in both richness and evenness suggests that migratory birds and specialists, which were common at the beginning of the study, have decreased in abundance and some species have been lost or replaced by more abundant species.

Our results show that bird abundance has decreased for many different kinds of species. Ballard, Geupel, Nur, and Gardali (2003) had similar findings in their 20-year mist-netting study in central coastal California, with 16 of 31 species undergoing significant declines and no species increasing in abundance. We document declining trends in both migratory and resident species, and in typical urban ‘avoiders’ and urban ‘invaders’ (i.e., species that typically respond differently to urbanization, Marzluff & Rodewald, 2008). Both urban avoiders that migrate (e.g., Brewer’s Sparrow, *Spizella breweri*; Northern Cardinal, and Yellow Warbler) and urban avoiders that are resident (e.g., Black-Tailed Gnatcatcher, *Polioptila melanura*; and Black-Throated Sparrow) experience declining trends. The latter species are consistent with recently observed patterns of decline among desert and aridland species across North America (Sauer, Link, Fallon, Pardieck, & Ziolkowski, 2013). It is more surprising, however, that we find declines in many common resident, typical urban-dwelling species in our study (e.g., House

Finch, *Haemorhous mexicanus*, Mourning Dove, and House Sparrow). Mourning Doves are the most abundant species in our study and are widespread across the United States (Sauer et al., 2013). Data from the North American Breeding Bird Survey indicate slight declines in Mourning Doves of 0.4% per year (Sauer et al., 2013), suggesting that our findings are only partly reflective of broader scale trends for that species. In our study, only Canada Geese (*Branta canadensis*) increased over time, which mirrors the national trend for increases in urban geese populations (Smith, Craven, & Curtis, 1999). We suggest that future research address whether these patterns indeed represent regional trends or patterns inherent to urban ecosystems.

4.2. Drying conditions affect riparian habitats and birds

Similar to global human burdens on freshwater, Arizona and the southwest USA are projected to increase water demand and water supplies are projected to decrease due to climate change (Hawkins & Ellis, 2010). Arid regions throughout the world are projected to become warmer and drier, leading to higher frequency and intensity of drought (IPCC, 2007). Bird diversity is often associated with perennial flows in arid riparian systems (Merritt & Bateman, 2012). Therefore, groundwater losses that negatively influence the distribution and quality of riparian forests will also negatively affect resident and migratory bird habitat (Brand, Stromberg, Goodrich, Dixon, Lansey, et al., 2011).

Wetlands in the arid southwest USA have experienced dramatic declines in extent (Weisberg, Mortenson, & Dilts, 2013). Within urban areas, discharge from municipal outflows (e.g., storm drains) along arid streams can provide hydrological conditions necessary for sustaining threatened wetland and riparian habitats (Bateman et al., 2015). A two year study along the Salt River in Phoenix found that areas which maintain riparian and wetland habitats

from both passive and active restoration have abundant and diverse biotic communities, irrespective of the source of water (Bateman et al., 2015). Taken together, these studies document the relative importance of water quantity for habitat and bird diversity.

In this study, Phoenix riparian sites with perennial flows are more similar in bird community composition and support the greatest abundance of birds compared to sites with ephemeral water. At the site-level, both perennial riparian types are associated with high levels of water and wetland cover. As such, perennial sites harbor more aquatic and shoreline-associated species compared to ephemeral sites. These birds may be attracted to resources like food, water, and cover that may be lacking at drier sites. Habitat structure also varied between the perennial riparian types, possibly accounting for why migratory songbirds were more common in perennial-natural sites compared to perennial-engineered sites. Our data and other studies from this arid region suggest that natural areas with tall vegetation and dense canopy cover support songbird habitat, similar to reaches along the Salt River (Bateman et al., 2015) and non-urban streams in central Arizona (Brand et al., 2011; Merritt & Bateman, 2012).

Although high bird abundances at perennial sites suggest that areas with aquatic habitats are important for maintaining urban biota, we did observe an important shift in bird community composition over time. Interestingly, the composition of bird communities across all sites has become more similar to the composition found at ephemeral-engineered sites. This could suggest that even the perennial sites are experiencing habitat loss, which could contribute to the overall reduction in abundance of riparian birds, as well as, the change in community assemblage over time.

In this study, we found the greatest decreases in birds at ephemeral compared to perennial sites. Even though we found more birds and more species at perennial sites, the importance of ephemeral riparian areas is not to be overlooked in aridland ecosystems (Katz, Denslow, and Stromberg, 2012). For example, non-perennial streams may represent vegetation and habitat available to both Sonoran Desert species and riparian obligate species. Future research should investigate if the mechanisms for bird declines varies among riparian types.

4.3. Land cover and habitat change

Although we do not have direct measures of land cover change around our sites, Phoenix has experienced both rapid urban expansion (Kane, Connors, & Galletti, 2014) as well as urban intensification over the past several decades (Stefanov, Netzband, Möller, Redman, & Mack, 2007). In Phoenix and other metropolitan areas, urban areas are increasingly moving from a patchwork of agriculture and rural/residential yards to become more ‘filled in’ by impervious surfaces with low vegetation cover (Stefanov et al., 2007; Tratalos, Fuller, Warren, Davies, & Gaston, 2007). While for some species, the decline we observe may be part of regional trends, declines in common, resident urban-dwelling species leads us to suspect that urbanization has played a significant role. This view is bolstered by the clear shift in community composition that we observe across riparian types toward the more urban-dwelling species found in ephemeral-engineered sites. This suggests that urbanization in areas surrounding riparian sites is contributing to declines in abundance and species richness as well as shifts in species composition. Similarly, other studies have quantified shifts in bird communities related to the modification of land cover. For example, a study in Great Britain found that urban intensification or ‘densification’ is associated with declines in bird densities (Tratalos, Fuller, Evans, Davies,

Newson, et al., 2007). Another study in Massachusetts documenting bird community shifts over 150 years, found shifts toward more typical urban dwelling species and away from forest specialist species during a period in which wooded urban areas became progressively more densely populated (Strohbach et al., 2014).

In our study, riparian types with ephemeral water have features that describe the openness of the habitat and support bird species associated with the Sonoran Desert (e.g., Gambel's Quail, and Curve-billed Thrasher). However, the openness found in engineered sites is comprised of impervious surfaces; whereas, natural sites have bare ground. Desert specialist species, such as Phainopepla (*Phainopepla nitens*), are present only at ephemeral-natural sites, highlighting the importance of preserving natural open spaces. A study in Berkeley, California, USA, suggested that green spaces serve to mitigate for loss of biodiversity by supporting specialist species in urban areas (Shultz, Tingley, & Bowie, 2012). Perhaps natural sites in Phoenix may serve as refugia for specialist species intolerant of a landscape dedicated to the built environment. We suggest additional research evaluate species-habitat relations and document modification to vegetation cover and open space over time.

5. Conclusions

Our results indicate that, over the last decade, several species have been lost, and many common and rare birds are experiencing declining abundances in riparian zones of the greater Phoenix metropolitan area and nearby surrounding Sonoran Desert. These declines tend to be greater in more natural sites compared to human-influenced, engineered sites. Bird communities respond to degree of water permanence in this arid city. Perennial sites are important because they provide habitat for a range of species, including aquatic and marshland birds, as well as,

328 migratory songbirds. Engineered riparian sites in Phoenix appear to be surrounded by greater
329 impervious surface cover and are associated with more typical urban-dwelling species. By
330 contrast, natural sites support more specialists such as migratory songbirds and Sonoran Desert
331 species. However, the decadal declines we found for species using these natural sites suggest that
332 they may be sensitive to increased urban expansion or intensification in the areas surrounding
333 natural riparian sites. Taken together, our study and others of riparian sites in Phoenix, suggest
334 the following measures to maintain diverse and abundant riparian bird communities in the city:
335 (1) preserving natural areas with high amounts of tall vegetation and dense canopy cover (for
336 migratory songbirds), (2) retaining natural areas with bare ground (for upland Sonoran Desert
337 species), and (3) maintaining or restoring habitats with perennial flows to support a diverse urban
338 bird assemblage.

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Table 1. Bird abundance during spring and winter at 12 sites across four riparian types in central Arizona, USA, based on Bayesian analyses. Riparian types vary by water permanence and degree of human influence: ephemeral-engineered (EE), ephemeral-natural (EN), perennial-engineered (PE), and perennial-natural (PN). Mean and trend in abundance with lower and upper credible intervals (CIs) derived from a Bayesian model (model fit $R^2 = 0.41$, model under predicted points at high abundance) for the beginning (2001) and the end (2013) of the study period. Trend is the percent change in abundance per year, or the total percent change in abundance over the period of the study (12 years), with significant changes in bold.

Riparian type	Spring			
	Early (2001) Mean (CIs)	Recent (2013) Mean (CIs)	Per year Trend in % (CIs)	Over 12 yrs Trend in % (CIs)
ephemeral-engineered	23.9 (22.3, 25.6)	14.8 (13.7, 15.9)	-3.9 (-4.9, -3.0)	-38.2 (-45.5, -30.2)
ephemeral-natural	20.4 (18.2, 22.7)	7.3 (6.3, 8.3)	-8.2 (-9.8, -6.6)	-64.3 (-71.1, -55.8)
perennial-engineered	49.1 (46.7, 51.7)	53.4 (50.7, 56.3)	0.7 (0.0, 1.4)	8.9 (0.2, 18.3)
perennial-natural	25.6 (23.6, 27.7)	12.7 (11.6, 13.9)	-5.7 (-6.9, -4.6)	-50.5 (-57.4, -42.9)
Engineered (EE + PE)	34.3 (32.8, 35.8)	28.1 (24.9, 31.5)	-1.6 (-2.3, -1.0)	-18.0 (-24.0, -11.8)
Natural (EN + PN)	22.8 (21.4, 24.4)	9.6 (7.9, 11.7)	-7.0 (-8.0, -5.9)	-58.0 (-63.1, -52.0)
Perennial (PE + PN)	35.5 (33.8, 37.2)	26.0 (22.8, 29.7)	-2.5 (-3.2, -1.9)	-26.6 (-32.6, -20.2)
Ephemeral (EE + EN)	22.1 (20.6, 23.5)	10.4 (8.6, 12.5)	-6.1 (-7.1, -5.1)	-53.0 (-58.5, -46.9)
Riparian type	Winter			
	Early (2001) Mean (CIs)	Recent (2013) Mean (CIs)	Per year Trend in % (CIs)	Over 12 yrs Trend in % (CIs)
ephemeral-engineered	24.2 (22.6, 26.0)	13.7 (12.6, 14.8)	-4.6 (-5.6, -3.7)	-43.4 (-50.2, -36.3)
ephemeral-natural	12.9 (11.3, 14.8)	6.8 (5.8, 7.8)	-5.2 (-7.2, -3.3)	-47.6 (-59.2, -33.3)
perennial-engineered	80.5 (77.3, 83.9)	65.4 (62.5, 68.3)	-1.7 (-2.3, -1.1)	-18.8 (-24.2, -12.9)
perennial-natural	46.8 (43.8, 49.9)	19.0 (17.6, 20.5)	-7.2 (-8.1, -6.3)	-59.4 (-63.9, -54.4)
Engineered (EE + PE)	44.2 (42.4, 46.0)	29.9 (26.7, 33.5)	-3.2 (-3.8, -2.6)	-32.2 (-37.0, -27.1)
Natural (EN + PN)	24.6 (22.8, 26.5)	11.3 (9.2, 14.0)	-6.2 (-7.3, -5.2)	-53.9 (-59.9, -47.1)
Perennial (PE + PN)	61.4 (59.1, 63.9)	35.3 (31.7, 39.3)	-4.5 (-5.1, -4.0)	-42.6 (-46.3, -38.5)
Ephemeral (EE + EN)	17.7 (16.4, 19.1)	9.6 (7.8, 11.9)	-4.9 (-6.0, -3.9)	-45.5 (-52.5, -37.7)

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Fig. 1. Bird sampling locations at 12 riparian sites in the greater Phoenix metropolitan area and surrounding Sonoran Desert, Arizona, USA.

Fig. 2. Spring and winter bird abundances (3-year moving averages) and species richness (3-year moving averages) with standard error bars per riparian type (12 sites) in central Arizona, USA.

Fig. 3. Ordinations of the riparian bird community showing temporal shifts in community structure during spring and winter over the period of the study (12 years) at 12 sites in central Arizona, USA.

Fig. 4. Significant environmental variables (arrows) describing habitat characteristics across four riparian types (12 sites in central Arizona, USA) are depicted on spring bird ordination of recent years (2011-2013).

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Fig. 1. Bird sampling locations at 12 riparian sites in the greater Phoenix metropolitan area and surrounding Sonoran Desert, Arizona, USA. Sampling locations are overlaid on a map of 2011 land cover of the region, modified from the National Land Cover Database (Homer, Dewitz, Yang, Jin, Danielson, et al., 2015). Riparian sampling locations differ in water permanence (ephemeral or perennial) and degree of human influence (engineered or natural).

Fig. 2. Spring and winter bird abundances (3-year moving averages) and species richness (3-year moving averages) with standard error bars per riparian type (12 sites) in central Arizona, USA. Abundance is maximum number of each species observed (among three seasonal visits) per site and averaged across the 3 years. Period 1 is the 3-year average for years 2001, 2002, 2004; period 10 is the 3-year average for years 2011-2013. Riparian types vary by water permanence and degree of human influence: ephemeral-engineered (EE), ephemeral-natural (EN), perennial-engineered (PE), and perennial-natural (PN).

Fig. 3. Ordinations of the riparian bird community showing temporal shifts in community structure during spring and winter over the period of the study (12 years) at 12 sites in central Arizona, USA. Riparian types vary by water permanence and degree of human influence: ephemeral-engineered (EE), ephemeral-natural (EN), perennial-engineered (PE), and perennial-natural (PN). Ellipses represent the core of the overall riparian bird community for each temporal period (3-year moving averages), from period 1 (average of 2001, 2002, 2004, depicted in light yellow) to period 10 (average of 2011-2013, depicted in dark red). Trajectory of ellipses depicts the change in bird assemblages over time.

Fig. 4. Significant environmental variables (arrows) describing habitat characteristics across four riparian types (12 sites in central Arizona, USA) are depicted on spring bird ordination of recent years (2011-2013). The direction of the arrow indicates an increase of that variable. Refer to Appendix E for environmental variables codes and descriptions. Ellipses represent the core of the bird communities for each riparian type. Riparian types vary by water permanence and degree of human influence: ephemeral-engineered (EE), ephemeral-natural (EN), perennial-engineered (PE), and perennial-natural (PN). Axis 1 and 2 of ordination show differences at the landscape- and site-levels across riparian types. Axis 3 of ordination shows differences among the perennial types at the site-level.

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Appendix B. Ordinations of bird communities at 12 sites across four riparian types in central Arizona, USA.

Appendix C. List of bird common and scientific names and four-letter alpha codes of species observed at 12 riparian sites from 2001-2013 in central Arizona, USA.

Appendix D. Diversity profiles of bird communities found at four riparian types (12 sites) in central Arizona, USA, for spring and winter of early and recent time frames.

Appendix E. Environmental variables measured at 12 sites across four riparian types in central Arizona, USA.

Appendix A. Bird species richness during spring and winter at 12 sites across four riparian types in central Arizona, USA, based on Bayesian analyses. Riparian types vary by water permanence and degree of human influence: ephemeral-engineered (EE), ephemeral-natural (EN), perennial-engineered (PE), and perennial-natural (PN). Mean and trend in species richness with lower and upper credible intervals (CIs) derived from a Bayesian model (model fit $R^2 = 0.45$) for the beginning (2001) and the end (2013) of the study period. Trend is the percent change in richness per year, or the total percent change in richness over the period of the study (12 years), with significant changes in bold.

Riparian type	Spring			
	Early (2001) Mean (CIs)	Recent (2013) Mean (CIs)	Per year Trend in % (CIs)	Over 12 yrs Trend in % (CIs)
ephemeral-engineered	9.5 (8.5, 10.6)	6.5 (5.7, 7.2)	-3.2 (-4.7, -1.7)	-32.0 (-43.7, -18.3)
ephemeral-natural	9.7 (8.3, 11.4)	3.6 (2.9, 4.4)	-7.8 (-10.2, -5.5)	-62.5 (-72.6, -49.6)
perennial-engineered	13.6 (12.2, 15.1)	9.1 (8.1, 10.2)	-3.3 (-4.7, -1.8)	-33.0 (-43.8, -19.5)
perennial-natural	13.1 (11.7, 14.6)	6.6 (5.8, 7.6)	-5.5 (-7.1, -3.9)	-49.3 (-58.6, -38.0)
Engineered (EE + PE)	11.4 (10.5, 12.2)	7.7 (6.2, 9.5)	-3.2 (-4.3, -2.1)	-32.5 (-40.9, -22.7)
Natural (EN + PN)	11.3 (10.3, 12.4)	4.9 (3.7, 6.4)	-6.7 (-8.1, -5.3)	-56.4 (-63.7, -48.2)
Perennial (PE + PN)	13.3 (12.3, 14.4)	7.8 (6.2, 9.6)	-4.4 (-5.5, -3.3)	-41.7 (-49.4, -33.1)
Ephemeral (EE + EN)	9.6 (8.7, 10.6)	4.9 (3.6, 6.4)	-5.5 (-7.0, -4.1)	-49.5 (-58.2, -39.8)
Riparian type	Winter			
	Early (2001) Mean (CIs)	Recent (2013) Mean (CIs)	Per year Trend in % (CIs)	Over 12 yrs Trend in % (CIs)
ephemeral-engineered	8.4 (7.4, 9.5)	4.8 (4.2, 5.5)	-4.5 (-6.2, -2.8)	-42.7 (-53.8, -29.1)
ephemeral-natural	7.3 (6.0, 8.7)	3.5 (2.8, 4.3)	-6.0 (-8.5, -3.4)	-52.2 (-65.7, -33.9)
perennial-engineered	14.5 (13.1, 16.0)	10.8 (9.7, 12.0)	-2.5 (-3.9, -1.1)	-25.9 (-37.6, -12.2)
perennial-natural	12.1 (10.7, 13.8)	6.1 (5.3, 7.0)	-5.5 (-7.3, -3.8)	-49.6 (-59.7, -37.3)
Engineered (EE + PE)	11.0 (10.2, 11.9)	7.2 (5.8, 9.0)	-3.5 (-4.6, -2.4)	-34.8 (-43.4, -24.9)
Natural (EN + PN)	9.4 (8.4, 10.5)	4.6 (3.4, 6.3)	-5.8 (-7.3, -4.2)	-50.9 (-60.0, -40.3)
Perennial (PE + PN)	13.3 (12.3, 14.4)	8.1 (6.5, 10.1)	-4.0 (-5.1, -2.9)	-38.8 (-46.8, -29.7)
Ephemeral (EE + EN)	7.8 (7.0, 8.7)	4.1 (3.0, 5.6)	-5.2 (-6.8, -3.6)	-47.6 (-57.1, -35.9)

Appendix B. Ordinations of bird communities at 12 sites across four riparian types in central Arizona, USA. Riparian types vary by water permanence and degree of human influence: ephemeral-engineered (EE), ephemeral-natural (EN), perennial-engineered (PE), and perennial-natural (PN). Community composition varied by seasons and types during spring and winter from 2001 to 2013. Top panel ordination axis 3 separates bird species (four-letter alpha codes from Pyle & DeSante, 2013; Appendix E) by seasons. On lower panels, axis 1 separates birds based on water presence and axis 2 separates birds based on degree of human influence. Ellipses on lower panels represent the core of bird communities per type.

Spring Riparian Type NMDS

Winter Riparian Type NMDS

Appendix C. List of bird common and scientific names and four-letter alpha codes (according to Pyle & DeSante, 2013) of species observed at 12 riparian sites from 2001-2013 in central Arizona, USA. For each species, early (2001, 2002, 2004) and recent (2011-2013) abundances for spring and winter are presented. Abundance is the sum for all sites of the maximum number of each species observed among three seasonal annual visits per site during a 3-year period (early and recent). Abundances with zero values indicate species was observed in study but not during early or recent period. Bolding indicates species with significantly different ($p < 0.05$) counts in early versus recent period based on Pearson's Phi Coefficient of Association generated using program R stats version 3.1.1 with indicpecies package (De Caceres & Legendre, 2009).

Common name	Scientific name	Code	Spring		Winter	
			Early abundance	Recent abundance	Early abundance	Recent abundance
Abert's Towhee	<i>Melospiza aberti</i>	ABTO	58	55	68	50
Acorn Woodpecker	<i>Melanerpes formicivorus</i>	ACWO	0	1	0	0
American Avocet	<i>Recurvirostra americana</i>	AMAV	10	10	0	0
American Bittern	<i>Botaurus lentiginosus</i>	AMBI	0	0	1	0
American Coot	<i>Fulica americana</i>	AMCO	40	13	123	30
American Crow	<i>Corvus brachyrhynchos</i>	AMCR	0	1	0	0
American Goldfinch	<i>Spinus tristis</i>	AMGO	0	2	11	0
American Kestrel	<i>Falco sparverius</i>	AMKE	3	0	5	3
American Pipit	<i>Anthus rubescens</i>	AMPI	0	0	0	0
American Wigeon	<i>Anas americana</i>	AMWI	0	5	94	22
Anna's Hummingbird	<i>Calypte anna</i>	ANHU	28	25	38	30

Ash-throated Flycatcher	<i>Myiarchus cinerascens</i>	ATFL	24	4	3	0
Bald Eagle	<i>Haliaeetus leucocephalus</i>	BAEA	2	0	4	2
Bank Swallow	<i>Riparia riparia</i>	BANS	0	0	0	0
Barn Swallow	<i>Hirundo rustica</i>	BARS	0	0	0	0
Bell's Vireo	<i>Vireo bellii</i>	BEVI	10	4	0	0
Belted Kingfisher	<i>Megasceryle alcyon</i>	BEKI	7	5	11	12
Bendire's Thrasher	<i>Toxostoma bendirei</i>	BETH	1	0	0	0
Bewick's Wren	<i>Thryomanes bewickii</i>	BEWR	8	1	6	7
Black Phoebe	<i>Sayornis nigricans</i>	BLPH	11	3	20	10
Black Vulture	<i>Coragyps atratus</i>	BLVU	2	0	0	0
Black-and-white Warbler	<i>Mniotilta varia</i>	BAWW	0	0	1	0
Black-chinned Hummingbird	<i>Archilochus alexandri</i>	BCHU	11	1	0	0
Black-chinned Sparrow	<i>Spizella atrogularis</i>	BCSP	0	0	0	1
Black-crowned Night Heron	<i>Nycticorax nycticorax</i>	BCNH	24	2	38	6
Black-headed Grosbeak	<i>Pheucticus melanocephalus</i>	BHGR	0	0	0	0
Black-necked Stilt	<i>Himantopus mexicanus</i>	BNST	55	5	27	227
Black-tailed Gnatcatcher	<i>Poliophtila melanura</i>	BTGN	15	2	18	2
Black-throated Gray Warbler	<i>Setophaga nigrescens</i>	BTYW	0	0	1	0

Black-throated Sparrow	<i>Amphispiza bilineata</i>	BTSP	26	1	17	1
Blue-gray Gnatcatcher	<i>Polioptila caerulea</i>	BGGN	5	0	3	0
Blue-winged Teal	<i>Anas discors</i>	BWTE	4	0	2	0
Brewer's Blackbird	<i>Euphagus cyanocephalus</i>	BRBL	6	0	0	0
Brewer's Sparrow	<i>Spizella breweri</i>	BRSP	103	10	74	0
Bridled Titmouse	<i>Baeolophus wollweberi</i>	BRTI	0	0	0	0
Bronzed Cowbird	<i>Molothrus aeneus</i>	BROC	0	0	0	0
Brown Pelican	<i>Pelecanus occidentalis</i>	BRPE	0	0	0	1
Brown-crested Flycatcher	<i>Myiarchus tyrannulus</i>	BCFL	1	0	0	0
Brown-headed Cowbird	<i>Molothrus ater</i>	BHCO	58	23	0	6
Bufflehead	<i>Bucephala albeola</i>	BUFF	0	0	1	0
Bullock's Oriole	<i>Icterus bullockii</i>	BUOR	7	0	0	0
Burrowing Owl	<i>Athene cunicularia</i>	BUOW	0	0	0	0
Bushtit	<i>Psaltiriparus minimus</i>	BUSH	2	0	0	0
Cactus Wren	<i>Campylorhynchus brunneicapillus</i>	CACW	22	4	20	8
Canada Goose	<i>Branta canadensis</i>	CANG	0	35	118	172
Canvasback	<i>Aythya valisineria</i>	CANV	0	0	0	7
Canyon Towhee	<i>Melospiza fusca</i>	CANT	0	0	1	2

Canyon Wren	<i>Catherpes mexicanus</i>	CANW	0	0	0	0
Cassin's Vireo	<i>Vireo cassinii</i>	CAVI	2	0	3	0
Cattle Egret	<i>Bubulcus ibis</i>	CAEG	0	0	0	0
Chestnut-collared Longspur	<i>Calcarius ornatus</i>	CCLO	0	0	3	0
Chinese Goose / Domestic Swan Goose	<i>Anser cygnoides</i>	CHGO	0	0	0	0
Chipping Sparrow	<i>Spizella passerina</i>	CHSP	2	2	0	0
Cinnamon Teal	<i>Anas cyanoptera</i>	CITE	10	10	4	10
Cliff Swallow	<i>Petrochelidon pyrrhonota</i>	CLSW	0	0	0	0
Common Gallinule	<i>Gallinula galeata</i>	COGA	9	2	6	1
Common Goldeneye	<i>Bucephala clangula</i>	COGO	0	0	0	0
Common Merganser	<i>Mergus merganser</i>	COME	0	0	3	10
Common Nighthawk	<i>Chordeiles minor</i>	CONI	0	8	0	0
Common Raven	<i>Corvus corax</i>	CORA	18	12	21	19
Common Yellowthroat	<i>Geothlypis trichas</i>	COYE	17	17	18	2
Cooper's Hawk	<i>Accipiter cooperii</i>	COHA	2	5	1	7
Cordilleran Flycatcher	<i>Empidonax occidentalis</i>	COFL	1	1	0	0
Costa's Hummingbird	<i>Calypte costae</i>	COHU	10	3	8	1

Crissal Thrasher	<i>Toxostoma crissale</i>	CRTH	0	0	0	0
Curve-billed Thrasher	<i>Toxostoma curvirostre</i>	CBTH	13	22	20	16
Dark Eyed Junco	<i>Junco hyemalis</i>	DEJU	0	0	22	0
Domestic Duck	<i>Anas platyrhyncha domesticus</i>	DODU	0	0	0	0
Domestic Greylag Goose	<i>Anser anser</i>	DOGO	0	13	0	0
Double-crested Cormorant	<i>Phalacrocorax auritus</i>	DCCO	26	46	61	53
Downy Woodpecker	<i>Picoides pubescens</i>	DOWO	0	0	1	0
Eared Grebe	<i>Podiceps nigricollis</i>	EAGR	3	1	0	4
Eurasian Collared- Dove	<i>Streptopelia decaocto</i>	EUCD	0	2	0	0
European Starling	<i>Sturnus vulgaris</i>	EUST	5	10	5	5
Gadwall	<i>Anas strepera</i>	GADW	2	0	0	19
Gambel's Quail	<i>Callipepla gambelii</i>	GAQU	75	64	26	20
Gila Woodpecker	<i>Melanerpes uropygialis</i>	GIWO	21	4	18	4
Gilded Flicker	<i>Colaptes chrysoides</i>	GIFL	0	1	2	0
Glossy Ibis	<i>Plegadis falcinellus</i>	GLIB	0	0	0	0
Gray Flycatcher	<i>Empidonax wrightii</i>	GRFL	0	0	0	0
Great Blue Heron	<i>Ardea herodias</i>	GBHE	34	84	43	98
Great Egret	<i>Ardea alba</i>	GREG	30	20	78	136

Great Horned Owl	<i>Bubo virginianus</i>	GHOW	1	1	0	2
Greater Roadrunner	<i>Geococcyx californianus</i>	GRRO	1	6	0	0
Greater Yellowlegs	<i>Tringa melanoleuca</i>	GRYE	3	5	24	5
Great-tailed Grackle	<i>Quiscalus mexicanus</i>	GTGR	92	50	78	61
Green Heron	<i>Butorides virescens</i>	GRHE	13	5	9	3
Green-tailed Towhee	<i>Pipilo chlorurus</i>	GTTO	2	1	2	0
Green-winged Teal	<i>Anas crecca</i>	GWTE	0	0	15	24
Hairy Woodpecker	<i>Picoides villosus</i>	HAWO	0	0	0	0
Hammond's Flycatcher	<i>Empidonax hammondii</i>	HAFL	0	0	0	0
Harris' Hawk	<i>Parabuteo unicinctus</i>	HASH	0	0	1	2
Hermit Thrush	<i>Catharus guttatus</i>	HETH	0	0	0	0
Hermit Warbler	<i>Setophaga occidentalis</i>	HEWA	1	0	0	0
Hooded Merganser	<i>Lophodytes cucullatus</i>	HOME	0	0	0	0
Hooded Oriole	<i>Icterus cucullatus</i>	HOOR	1	3	0	0
Horned Lark	<i>Eremophila alpestris</i>	HOLA	0	0	0	0
House Finch	<i>Haemorhous mexicanus</i>	HOFI	129	71	127	20
House Sparrow	<i>Passer domesticus</i>	HOSP	124	34	74	22
House Wren	<i>Troglodytes aedon</i>	HOWR	0	0	1	3

Inca Dove	<i>Columbina inca</i>	INDO	11	2	5	0
Killdeer	<i>Charadrius vociferus</i>	KILL	76	57	83	63
Ladder-backed Woodpecker	<i>Picoides scalaris</i>	LBWO	8	4	10	5
Lark Sparrow	<i>Chondestes grammacus</i>	LASP	3	14	0	0
Lazuli Bunting	<i>Passerina amoena</i>	LAZB	3	1	0	0
Least Sandpiper	<i>Calidris minutilla</i>	LESA	37	0	81	54
Lesser Goldfinch	<i>Spinus psaltria</i>	LEGO	6	23	3	19
Lesser Nighthawk	<i>Chordeiles acutipennis</i>	LENI	0	8	0	0
Lesser Scaup	<i>Aythya affinis</i>	LESC	0	0	0	0
Lesser Yellowlegs	<i>Tringa flavipes</i>	LEYE	0	0	0	0
Lincoln's Sparrow	<i>Melospiza lincolnii</i>	LISP	1	0	7	0
Little Blue Heron	<i>Egretta caerulea</i>	LBHE	0	0	2	0
Loggerhead Shrike	<i>Lanius ludovicianus</i>	LOSH	3	0	6	0
Long-billed Curlew	<i>Numenius americanus</i>	LBCU	0	0	0	0
Long-billed Dowitcher	<i>Limnodromus scolopaceus</i>	LBDO	48	200	36	0
Lucy's Warbler	<i>Oreothlypis luciae</i>	LUWA	15	10	0	0
MacGillivray's Warbler	<i>Geothlypis tolmiei</i>	MGWA	8	0	0	0
Magnolia Warbler	<i>Setophaga magnolia</i>	MAWA	0	0	0	0

Mallard	<i>Anas platyrhynchos</i>	MALL	109	96	161	257
Marsh Wren	<i>Cistothorus palustris</i>	MAWR	6	1	16	6
Merlin	<i>Falco columbarius</i>	MERL	1	1	0	0
Mountain Bluebird	<i>Sialia currucoides</i>	MOBL	0	0	0	1
Mourning Dove	<i>Zenaida macroura</i>	MODO	102	46	98	44
Neotropic Cormorant	<i>Phalacrocorax brasilianus</i>	NECO	6	33	9	12
Northern Cardinal	<i>Cardinalis cardinalis</i>	NOCA	20	1	7	3
Northern Flicker	<i>Colaptes auratus</i>	NOFL	6	0	12	4
Northern Harrier	<i>Circus cyaneus</i>	NOHA	0	0	2	4
Northern Mockingbird	<i>Mimus polyglottos</i>	NOMO	17	9	12	4
Northern Pintail	<i>Anas acuta</i>	NOPI	0	1	235	11
Northern Rough-winged Swallow	<i>Stelgidopteryx serripennis</i>	NRWS	0	0	0	0
Northern Shoveler	<i>Anas clypeata</i>	NSHO	7	39	56	114
Orange-crowned Warbler	<i>Oreothlypis celata</i>	OCWA	9	8	26	5
Osprey	<i>Pandion haliaetus</i>	OSPR	1	1	2	3
Peregrine Falcon	<i>Falco peregrinus</i>	PEFA	1	0	2	0
Phainopepla	<i>Phainopepla nitens</i>	PHAI	9	3	19	9
Pied-billed Grebe	<i>Podilymbus podiceps</i>	PBGR	17	0	33	4

Pine Siskin	<i>Spinus pinus</i>	PISI	0	0	0	9
Plumbeous Vireo	<i>Vireo plumbeus</i>	PLVI	0	1	0	0
Pyrrhuloxia	<i>Cardinalis sinuatus</i>	PYRR	0	0	0	1
Redhead	<i>Aythya americana</i>	REDH	0	0	6	1
Red-naped Sapsucker	<i>Sphyrapicus nuchalis</i>	RNSA	0	0	1	0
Red-tailed Hawk	<i>Buteo jamaicensis</i>	RTHA	9	5	21	11
Red-winged Blackbird	<i>Agelaius phoeniceus</i>	RWBL	118	50	62	19
Ring-necked Duck	<i>Aythya collaris</i>	RNDU	0	9	35	84
Rock Pigeon	<i>Columba livia</i>	ROPI	2	0	0	24
Rock Wren	<i>Salpinctes obsoletus</i>	ROWR	4	1	4	0
Rosy-faced Lovebird	<i>Agapornis roseicollis</i>	RFLO	0	3	0	0
Ruby-crowned Kinglet	<i>Regulus calendula</i>	RCKI	2	0	23	28
Ruddy Duck	<i>Oxyura jamaicensis</i>	RUDU	1	0	9	1
Rufous-crowned Sparrow	<i>Aimophila ruficeps</i>	RCSP	1	0	0	0
Savannah Sparrow	<i>Passerculus sandwichensis</i>	SAVS	0	0	0	0
Say's Phoebe	<i>Sayornis saya</i>	SAPH	6	1	7	5
Sharp-shinned Hawk	<i>Accipiter striatus</i>	SSHA	0	0	1	2
Snow Goose	<i>Chen caerulescens</i>	SNGO	0	5	0	0

Snowy Egret	<i>Egretta thula</i>	SNEG	30	11	126	18
Song Sparrow	<i>Melospiza melodia</i>	SOSP	43	26	57	23
Sora	<i>Porzana carolina</i>	SORA	0	0	0	0
Spotted Sandpiper	<i>Actitis macularius</i>	SPSA	4	2	12	42
Spotted Towhee	<i>Pipilo maculatus</i>	SPTO	2	0	4	0
Summer Tanager	<i>Piranga rubra</i>	SUTA	0	0	0	0
Swamp Sparrow	<i>Melospiza georgiana</i>	SWSP	0	0	3	0
Townsend's Warbler	<i>Setophaga townsendi</i>	TOWA	2	0	0	0
Tree Swallow	<i>Tachycineta bicolor</i>	TRES	0	0	0	0
Turkey Vulture	<i>Cathartes aura</i>	TUVU	17	7	3	4
Vaux's Swift	<i>Chaetura vauxi</i>	VASW	0	0	0	0
Verdin	<i>Auriparus flaviceps</i>	VERD	70	76	66	55
Vermilion Flycatcher	<i>Pyrocephalus rubinus</i>	VEFL	2	0	1	0
Vesper Sparrow	<i>Pooecetes gramineus</i>	VESP	0	0	0	0
Violet-green Swallow	<i>Tachycineta thalassina</i>	VGSW	0	0	0	0
Virginia Rail	<i>Rallus limicola</i>	VIRA	1	0	0	0
Virginia's Warbler	<i>Oreothlypis virginiae</i>	VIWA	0	1	0	0
Warbling Vireo	<i>Vireo gilvus</i>	WAVI	0	1	0	0

Western Bluebird	<i>Sialia mexicana</i>	WEBL	0	4	0	0
Western Kingbird	<i>Tyrannus verticalis</i>	WEKI	5	3	0	0
Western Meadowlark	<i>Sturnella neglecta</i>	WEME	0	0	24	0
Western Sandpiper	<i>Calidris mauri</i>	WESA	7	0	2	0
Western Scrub-Jay	<i>Aphelocoma californica</i>	WESJ	0	0	1	0
Western Tanager	<i>Piranga ludoviciana</i>	WETA	0	0	0	0
Western Wood-Pewee	<i>Contopus sordidulus</i>	WEWP	0	0	1	0
White-breasted Nuthatch	<i>Sitta carolinensis</i>	WBNU	0	0	2	0
White-crowned Sparrow	<i>Zonotrichia leucophrys</i>	WCSP	32	14	148	60
White-faced Ibis	<i>Plegadis chihi</i>	WFIB	1	0	124	1
White-throated Swift	<i>Aeronautes saxatalis</i>	WTSW	0	0	0	0
White-winged Dove	<i>Zenaida asiatica</i>	WWDO	23	37	0	1
Willet	<i>Tringa semipalmata</i>	WILL	0	1	0	0
Wilson's Phalarope	<i>Phalaropus tricolor</i>	WIPH	7	0	0	0
Wilson's Snipe	<i>Gallinago delicata</i>	WISN	0	0	5	2
Wilson's Warbler	<i>Cardellina pusilla</i>	WIWA	24	12	2	0
Yellow Warbler	<i>Setophaga petechia</i>	YEWA	34	14	8	0
Yellow-Breasted Chat	<i>Icteria virens</i>	YBCH	0	1	0	0

Yellow-headed Blackbird	<i>Xanthocephalus xanthocephalus</i>	YHBL	1	0	0	0
Yellow-rumped Warbler	<i>Setophaga coronata</i>	YRWA	39	19	80	48
Yellow-throated Warbler	<i>Setophaga dominica</i>	YTWA	0	0	0	0
Zone-tailed Hawk	<i>Buteo albonotatus</i>	ZTHA	0	0	0	0

Appendix D. Diversity profiles (Rényi's index family) of bird communities found at four riparian types (12 sites) in central Arizona, USA, for spring and winter of early (2001, 2002, 2004) and recent (2011-2013) time frames. Riparian types vary by water permanence and degree of human influence: ephemeral-engineered (EE), ephemeral-natural (EN), perennial-engineered (PE), and perennial-natural (PN). Scale parameter (alpha) displayed along the x-axis range from diversity indices more sensitive to rare species (0) to diversity indices more sensitive to abundant species (Inf), therefore, as you move along alpha, rare species are weighted less. Shannon's entropy and Simpson's dominance index are related to alpha at 1 and 2, respectively (Tóthmérész, 1995).

Appendix E. Environmental variables measured at 12 sites across four riparian types in central Arizona, USA. Riparian types vary by water permanence (perennial or ephemeral) and degree of human influence (natural or engineered). Variables were measured during spring of 2013 in the field at the site-level (within 40-m radius around the point) and from 2010 remote-sensed images at the landscape-level (within a 1-km radius around the point).

Site-level variables	Description	Riparian types, mean (standard error)			
		Ephemeral-engineered	Ephemeral-natural	Perennial-engineered	Perennial-natural
Marsh_S	percent cover of marsh	8.2 (3.9)	0 (0)	11 (4)	6 (4.6)
Water_S	percent cover of water	1.5 (0.9)	0 (0)	11 (4)	26 (11.5)
Imperv_S	percent cover of impervious surface	8.2 (3.9)	7.5 (7.5)	6 (4.6)	5 (5)
Bare_S	percent cover of bare ground	61.9 (9.7)	50 (35)	42.7 (19.8)	11 (4)
LowVeg_S	proportion of vegetation at 0-0.6m in height from 10 random points	0.32 (0.02)	0.7 (0.3)	0.27 (0.03)	0.63 (0.17)
MedVeg_S	proportion of vegetation at 0.6-1.5m in height from 10 random points	0.25 (0.05)	0.5 (0.2)	0.43 (0.09)	0.37 (0.18)
HighVeg_S	proportion of vegetation at >1.5m in height from 10 random points	0.48 (0.06)	0.4 (0)	0.43 (0.07)	0.7 (0.06)
CC_S	percent canopy cover from 10 random points	42.4 (5.4)	27.5 (1.8)	52.9 (11.6)	61.6 (5.4)
Landscape-level variables					
Imperv_L	percent cover of impervious surface	40.5 (10.4)	2.5 (1.7)	21.7 (5.6)	1.6 (0.4)
Bare_L	percent cover of bare ground	47.8 (10.9)	68.8 (4.8)	46.3 (5.1)	50.8 (16.6)
Water_L	percent cover of water	1.6 (1.0)	4.3 (2.6)	11.7 (4.7)	10.6 (4)
Veg_L	percent cover of vegetation	10.1 (1.4)	24.4 (0.6)	15.2 (4.3)	32 (9.3)