ECOHYDROLOGY
*Ecohydrol.* **8**, 792–811 (2015)

(wileyonlinelibrary.com) DOI: 10.1002/eco.1560

# Novel water sources restore plant and animal communities along an urban river

H. L. Bateman,[1,3]* J. C. Stromberg,[2] M. J. Banville,[3] E. Makings,[2] B. D. Scott,[2]
A. Suchy[2] and D. Wolkis[2]

[1] *School of Letters and Sciences, Arizona State University, Mesa, AZ, 85212, USA*
[2] *School of Life Sciences, Arizona State University, Tempe, AZ, 85287-4501, USA*
[3] *Central Arizona–Phoenix Long-Term Ecological Research, Arizona State University, Tempe, AZ, 85287, USA*

## ABSTRACT

Many projects have been undertaken to restore urban rivers in arid regions. At the same time, passive discharge of urban water sources has stimulated redevelopment of wetlands and riparian forests along stretches of dewatered rivers. In Phoenix, Arizona, for example, some segments of the dewatered Salt River have been actively restored by planting and irrigation, whereas others have revegetated in response to runoff from storm drains and effluent drains. Our research documents how biotic communities differ between these actively restored and 'accidentally' restored areas, and between wetter and drier urban reaches. We addressed these objectives with a multi-taxa, multi-season sampling approach along reaches of the Salt River. We quantified plants using cover estimates in quadrats, birds using fixed radius, point-count surveys, and herpetofauna (amphibians and reptiles) using visual-encounter surveys. One notable finding was that wetland plants had greater richness and cover at accidentally restored sites compared with actively restored, dry urban, and non-urban reference sites. Birds and herpetofauna, however, were most species-rich at actively restored and non-urban reference sites, and riparian birds were more abundant at sites with perennial flows compared with ephemeral reaches. From a landscape perspective, the range of management approaches along the river (including laissez-faire) is sustaining a diverse riparian and wetland mosaic. Urban water subsidies are sustaining freshwater forests and marshlands, the latter a regionally declining ecosystem. In urbanized rivers of arid regions, mapping and conserving perennial stream flows arising from stormwater and effluent discharge can be an important complement to active restoration.

KEY WORDS aridland streams; birds; desert; accidental restoration; riparian vegetation; urban ecology; wetlands; wildlife

*Received 19 March 2014; Revised 3 September 2014; Accepted 11 September 2014*

## INTRODUCTION

As urban areas expand worldwide, there is a growing need to identify inexpensive and sustainable ways to restore riverine communities and the ecosystem services they provide (Bernhardt and Palmer, 2007; Everard and Moggridge, 2012). Urban rivers present a special challenge to restoration practitioners because of the extent to which their physical environments have been altered (Wenger *et al*., 2009; Hawley and Bledsoe, 2011). Restoration of appropriate flows of water and sediments is fundamental but can be strategically difficult and expensive to achieve (Arthington *et al*., 2010). Water resource development has been one of the causes for global declines in wetlands and riparian woodlands (Allan and Flecker, 1993; Dynesius and Nilsson, 1994). Although environmental flows are being released from upstream dams in some cities to restore seasonal flood pulses (Rood *et al*., 2005), a more basic challenge in many arid watersheds is to provide sufficient base flows for maintenance of these declining wetland and riparian ecosystems. Base flow release from upstream dams can be politically implausible, necessitating structure-based alternatives such as drip irrigation of planted trees (Gerlak *et al*., 2009; Bernhardt and Palmer, 2011).

A complementary approach to such purposeful or active restoration is to pursue protection of the many wetlands that have developed in response to urban water subsidies (Trammell *et al*., 2011). There are now many wetlands in arid regions that are sustained by leakage or outflows from agricultural or urban hydro-infrastructure (Briggs and Cornelius, 1998; Briggs and Cornelius, 1998; White and Stromberg, 2009; Sueltenfuss *et al*., 2013). However, the efficacy of storm drain outflow, municipal effluent, and other novel urban water sources for environmental restoration is only beginning to be explored (Brooks *et al*., 2006; Bijoor *et al*., 2012; Walsh *et al*., 2012; Scheffers and Paszkowski, 2013).

Developing suitable criteria for assessing restoration outcomes is yet another challenge for urban river restorationists. The biotic communities of urban rivers have

---

*Correspondence to: H. L. Bateman, School of Letters and Sciences, Arizona State University, Mesa, AZ 85212, USA.
E-mail: heather.bateman@gmail.com

undergone extensive change, and their novel species assemblages test the limits of traditional assessment rubrics (Dufour and Piégay, 2009). Overarching ecological objectives, such as increasing ecosystem functions or abundance of functional types, can be more appropriate than context-specific goals such as increased abundance of specific species (Bateman *et al*., 2012). Multi-taxa data are being increasingly utilized to capture the wide array of responses that are evident among broad taxonomic groups (Colwell and Coddington, 1994; Kotze and Samways, 1999; Dallimer *et al*., 2012).

One urban river in the American Southwest that has been extensively modified is the Salt. Upstream dams and diversion canals have enabled the development of an extensive irrigated and riparianized cityscape, but at great environmental cost (Rosenberg *et al*., 1987; Fitzhugh and Richter, 2004). To restore environmental amenities, portions of the river and its riparian zone have undergone active restoration, and others are targeted for restoration, pending appropriation of funds. Simultaneously, some sections of the Salt River have been 'accidentally' revitalized by the passive discharge of municipal effluent to the river bed, and by return of irrigation water and storm runoff into the river via storm drains. These water sources are sustaining wetland and riparian vegetation and wildlife (Rea, 1988; Makings *et al*., 2011; Banville and Bateman, 2012), but there has been no systematic comparison of biotic communities between actively restored areas and areas accidentally restored by novel urban water sources.

Using the Salt River in the Phoenix metropolitan area as our study area, we focused on plants, amphibians, reptiles, and birds to address the following questions: How similar are biotic communities at actively restored and accidentally rewatered urban river sites with respect to species diversity, composition, and abundance? How do these communities compare with those in non-restored, dry urban reaches and in non-urban reference areas? Are responses similar across taxonomic groups and across seasons? Our overall goal was to increase knowledge of the factors that influence riparian and wetland biota in urban freshwater ecosystems and thereby inform restoration and management. These issues are of particular importance given the increases in aridity that are projected to further reduce river base flows in the American Southwest and in other arid regions throughout the world (Seager *et al*., 2007; Palmer *et al*., 2009).

## MATERIALS AND METHODS

### *Study river*

The Salt River drains a watershed of 35 000 $km^2$ as it flows southwest from its head waters in mountainous north-central Arizona, through the Sonoran Desert, to its confluence with the Gila River west of Phoenix. The Salt River is part of the Colorado Basin that has been classified as vulnerable to impacts induced by climate change (Loaiciga, 2009). The region is arid with average annual maximum and minimum temperatures of 30 and 16 °C (Station 026486, Phoenix; WRCC, 2012), and annual precipitation of 20 cm.

During the 1800s, the Salt River flowed within a 3-km wide floodplain and sustained a variety of communities including marshes, riparian shrublands, and forests (Rea, 1983; Hendrickson and Minckley, 1984; Graf, 2000). In the early 1900s, the Salt River was dammed and flow-regulated upstream of Phoenix to provide water for irrigated agriculture and, increasingly, for municipal uses. The Salt River today is wholly diverted into a series of delivery canals at Granite Reef Diversion Dam, resulting in a desiccated river bed over much of its length through Phoenix (Figure 1; Appendix 1). Mean annual flow upstream of the diversion point is 28 000 cfs (USGS 09502000, Salt River below Stewart Mountain Dam; http://nwis.waterdata.usgs.gov). Mean annual and median flow in the center of the Phoenix metro area are, respectively, 196 and 8 cfs (USGS 09512165, Salt River at Priest Drive near Phoenix). Rains occur mainly in winter (November to March) and late summer (July to August), and the urbanized river undergoes periodic flood pulses in winter owing to stream flow releases from upstream dams during years with abundant winter rain and snow. Following large floods in the 1970s and 1980s, the river in the central city was channelized to increase flood water conveyance, creating a deeper and narrower river bed (Graf, 2000; Roberge, 2002). In the 1990s, a series of riparian restorations were planned, some of which were funded and implemented (Gerlak *et al*., 2009).

### *Study sites*

We established one or two study sites in each of six reach types: (1) non-urban reference, (2) mixed-use, actively restored, (3) actively restored urban, (4) semi-restored urban, (5) accidentally restored urban, all with perennial flow, and (6) dry urban reaches with ephemeral flow (Figure 1; Table I). Each site consisted of a 300-m long stretch of the river and its associated wetland and riparian zones. Site elevation ranged from 286 to 412 m.

Reference sites are useful in restoration planning and assessment but should be used carefully (Beauchamp and Shafroth, 2011; McClain *et al*., 2011). Our reference reach was intended as a contrast for the flow-regulated urban Salt River and thus was located in the flow-regulated portion of the river upstream of the city. Specifically, it was on the Tonto National Forest upstream of Granite Reef Diversion Dam, approximately 5 miles from the closest city boundary. Although stream flow is perennial, the magnitude and timing of flows have been altered by flow-regulating dams (Fenner *et al*., 1985). Reaches below dams often have reduced richness of plant species owing to disruption of longitudinal connectivity and reduction in spatio-temporal heterogeneity (Uowolo *et al*., 2005; Stromberg *et al*., 2012) and thus do not

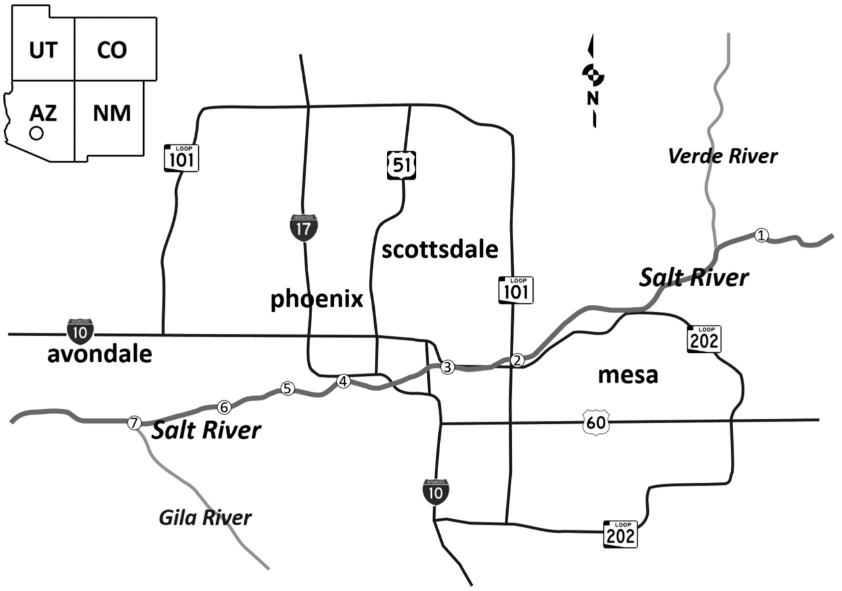

Figure 1. Study map of seven river reaches in central Arizona, which differ in levels of urbanization, water subsidy, and ecological restoration (defined in Tables I and II).

Table I. Location and attributes of study reaches along the Salt River in central Arizona.

| Reach name | Reach number | Reach type | Degree of urban | Elevation (m) | Latitude and longitude (decimal degrees) | | Mean transect length (m) |
|---|---|---|---|---|---|---|---|
| Tonto | 1 | Non-urban reference | 1 | 412 | 33·558948° | −111·958754° | 143[a] |
| Base and Meridian Wildlife Area | 7 | Mixed-use, restored | 2 | 286 | 33·384375° | −112·303177° | 386[a] |
| Phoenix Rio Salado | 4 | Urban, restored | 4 | 323 | 33·422419° | −112·075205° | 234 |
| Tempe Rio Salado | 3 | Urban, semi-restored | 4 | 347 | 33·434910° | −111·958754° | 261 |
| Price | 2 | Urban, accidentally restored | 4 | 360 | 33·437428° | −111·887722° | 119 |
| Ave 35 | 5 | Urban dry | 4 | 312 | 33·411469° | −112·133450° | 133 |
| Ave 67 | 6 | Urban dry | 3 | 300 | 33·395838 | −112·204064 | 130 |

Reach number refers to map in Figure 1.
[a] Transects extend on only one side of the river channel.

necessarily represent regional potential. Flow regulation has influenced stream hydrogeomorphology and the biotic communities of the reference site, creating sharply defined zones (a narrow wetland zone with abrupt transition to xeric floodplain) as it has been seen on other flow-regulated rivers in western USA (Merritt and Cooper, 2000). The floodplain on the Tonto National Forest was closed in the late 1970s to authorized grazing and in the early 1990s to off road vehicles but is occasionally grazed by livestock. The river and riparian vegetation are embedded within the Arizona Uplands Division of the Sonoran Desert (Brown, 1994) typified by xeric shrubs, succulents, and small desert legume trees.

The mixed-use, actively restored site is the Base and Meridian Wildlife Area (hereafter, B&M). B&M occupies a portion of the 11-km Tres Rios Ecosystem Restoration Project on the western fringe of Phoenix metropolitan area. The reach is surrounded by agriculture, commercial use, and undeveloped Sonoran Desert. B&M is managed by Arizona Game and Fish Department. In 2012, restoration efforts included earthmoving, vegetation clearing (non-native *Tamarix* shrubland), drip-line installation, tree, shrub and wetland emergent planting, and spraying of a tackifier for erosion control. These actions had been completed only a few months prior to our first sampling.

We selected two urban sites that were restored, although to varying degrees: Phoenix Rio Salado (PRS) in Phoenix at Central Avenue and Tempe Rio Salado (TRS) between the Tempe Town Lake Dam and Priest Drive. The PRS restoration area covers an 8-km stretch of the Salt River and was a partnership between the US Army Corps of Engineers and the City of Phoenix, which was completed in November 2005. The $100 million project expenses included earth recontouring, riverbed cleanup, drip irrigation, vegetation planting, low-flow channel stabilization, and construction of a groundwater delivery system to water the terrace forests and constructed wetlands. Among the riparian and upland trees planted and irrigated on terraces were *Celtis reticulata*, *Cercidium microphyllum*, *Chilopsis linearis*, *Populus fremontii*, *Prosopis pubescens*, *Prosopis velutina*, and *Salix gooddingii*. Several types of herbaceous wetland species were planted along pond edges. The low-flow channel has intermittent to perennial flow owing to outfall from storm drains located in the area. No tree plantings were made in the low-flow channel zone, although willows (*Salix* sp.) and other wetland plants have colonized the channel. We considered TRS to be a semi-restored site because many fewer trees were planted compared with PRS and tree plantings were within or immediately adjacent to the low-flow channel. Trees planted included *Fraxinus* sp., *P. fremontii*, *P. pubescens*, *P. velutina*, and *S. gooddingii*. Prior to the filling of the Tempe Town Lake in 1999, storm drains in the area were rerouted and combined, creating perennial flow from the drain located just below the dam (Boyd B, 2013, City of Tempe, pers. comm). At the time of sampling, the dominant vegetation type at TRS was an (unplanted) and dense *Typha* marshland. The low-flow channel at TRS is bordered by urban land including Sky Harbor International Airport. As part of management to reduce wildlife strikes, the airport actively mows and removes tall vegetation along this reach.

We defined one urban reach near Price drain as accidentally restored. The Price reach has perennial flows owing to a combination of water sources including discharge from one large drain (which includes drainage for a freeway interchange), multiple small storm drains, and until recently, the City of Mesa's Northwest Water Reclamation Plant. Water flows at the site also are influenced by the downstream barrier of the Tempe Town Lake rubber dam.

We identified two sites as dry urban reaches with ephemeral flow: 35th Avenue (Ave 35) and 67th Avenue (Ave 67) river crossings, in Phoenix (Figure 1). The river in both areas receives water discontinuously from storm drains. Ave 35 also receives water periodically from the City of Phoenix's 23rd Avenue Wastewater Treatment Plant.

### *Vegetation sampling*

We sampled vegetation within thirty 2-m$^2$ plots distributed along three cross-floodplain transects per site. The transects were between 100 and 250 m apart, and were approximately 125 m in cross-sectional width where riparian zones were narrow and nearly 400 m (on one side of the channel only) where the riparian zone was wide (Table I). Lateral boundaries of transects were delineated by vegetation indicators (transition from riparian to upland plant species) and geomorphic indicators (slope bases of channelized river sections). We sampled cover, by species, using cover classes. To capture phenological variation, we sampled during spring (March), summer dry season (June), and summer wet season (September) of 2012. (Vegetation at Ave 67 was sampled in 2013, and the spring season data at Price was collected in 2013 because access in 2012 was limited by localized flooding.) To further assess vegetation, we sampled aquatic plants in nine 1-m$^2$ plots per site; six of the plots were randomly located along edges of the stream channel, and three were in pools or side channels, if present. Plants were identified to species (where possible) using Kearney *et al.* (1960) and Vascular Plants of Arizona (VPA) (1992–2004). Nomenclature follows the US Department of Agriculture (USDA) Natural Resources Conservation Service PLANTS Database and recent revisions published in VPA (1992–2004) and Canotia (2004–2012). Voucher specimens were collected for most species and deposited in the Arizona State University Herbarium.

### *Bird sampling*

We sampled bird communities along three cross-floodplain transects per site. We established two stations per transect (six per site), and at each station, we counted birds seen and heard using 50-m fixed radius, 15-min point-count surveys. We surveyed during winter (January), spring (April), summer (June), and fall (October) 2013. One trained observer visited each station, and we reversed the order in which stations were surveyed between visits. Surveys were conducted under similar environmental conditions (i.e. no rain and wind from 0 to 3 on Beaufort scale) and were completed within 4 h of sunrise. We began surveys immediately upon arrival at the station and included birds flushed by the observer upon arrival. Observer recorded species on the basis of Sibley (2000) and classified according to Pyle and DeSante (2012). Bird minimum abundance (hereafter, abundance) was calculated as the greatest number of individuals of each species seen or heard at either station along each transect, per season. Because we did not individually mark animals, this method (of minimum abundance) conservatively estimated abundance and ensured that we did not count individuals twice.

### *Herpetofauna (amphibians and reptiles) sampling*

We quantified herpetofauna using daytime visual-encounter surveys similar to Banville and Bateman (2012) with the addition of flipping rocks to locate hidden individuals. We established three 10 × 20 m plots along each of the three transects (nine plots per site) to ensure equal sampling effort among sites. Because herpetofauna are mainly inactive during winter, we sampled during spring (March and April) and summer (June and September) 2013. We conducted surveys in the morning, during times of high diurnal herpetofauna activity, and under similar environmental conditions (i.e. warm, sunny, wind from 0 to 3 on Beaufort scale). Observers recorded species on the basis of Brennan and Holycross (2009) and classified according to Crother (2008). We defined herpetofauna minimum abundance (hereafter, abundance) as the greatest number of individuals of each species detected at one of the plots for each transect, per season.

### *Stream flow and water quality*

We characterized each site with respect to stream flow permanence and basic water quality parameters. We measured stream flow permanence by instrumenting sites with Maxim iButton temperature sensors (model #DS1921G) protected in waterproof capsules (model #DS9107). Temperature sensor fluctuations were manually compared with local temperature downloaded from Durango Station (Maricopa Flood Control Weather Gage 4700). Flow presence decisions were ground-truthed to field observations. We measured electrical conductivity of the surface water in the field at each transect during each sampling period using an Oakton Multiparameter PCSTestr 35.

### *Statistical analysis*

To contrast species richness among sites, we generated species accumulation curves (sample-based rarefaction) using EstimateS version 9.1 (Colwell, 2013). For plants, these curves were generated within seasons, using 30 plots per site. For birds and herpetofauna, curves were generated across four seasonal visits using nine plots for herpetofauna and six point-count stations for birds per site.

To assess compositional differences, we calculated relative abundance, by site, of organisms classified within habitat preference guilds (Verberk *et al.*, 2013). For example, we classified plant species according to their wetland indicator class: wetland species were those with designations of obligate wetland or facultative wetland as listed in the USDA Natural Resources Conservation Service PLANTS Database, USDA NRSC (2010); mesic species were those with facultative or facultative upland status; and dryland (or xeric) species had adaptations to dry environments. We classified bird species according to main habitat associations (Corman and Wise-Gervais, 2005). Riparian species are terrestrial birds associated (not obligatory) with floodplain forests (e.g. *Populus*, *Prosopis*, and *Salix*). Marshland/aquatic species are birds associated with marshlands or bodies of water. Desert birds are species associated with shrubs and cacti of the Sonoran Desert. Urban species are habitat generalists associated with human habitation or structures. Birds in the 'other' category included raptors and terrestrial passerine species.

To compare abundance across study sites, we used a repeated measures General Linear Model (GLM; SPSS version 20.0). Within-subject factors included seasons, and between-subject factors included sites. We used Tukey post-hoc tests for multiple comparisons of significant factors. We analysed only spring (March and April) and summer (June and September) seasons for herpetofauna because they are inactive during winter. We analysed winter (January), spring (April), summer (June), and fall (October) for bird species. We further analysed bird abundance by evaluating differences for species specifically affiliated with riparian areas. Because species in the riparian guild are mostly migratory, we included only spring and summer bird counts. For the plant analysis of variance, we included spring, early summer, and late summer data; the between-subject factor was site.

To further determine how plant and animal species community composition varied by site and season, we performed non-metric multidimensional scaling (NMDS; unconstrained ordination) using R stats version 3.0 with Vegan package (Oksanen *et al.*, 2013). We used a permutation procedure to fit environmental variables (stream flow permanence and degree of urbanization; Table I) onto the ordinations. Significance values of environmental vectors reveal which variables explain differences between sites on the basis of their location on the ordination graph.

## RESULTS

### *Stream flow*

The stream flow was perennial in most sites (Table II). At PRS, stream flow was perennial at two of three transects and absent at one transect during summer. The stream at both of the dry sites had surface water <10% of the year. Flowing water was present during the spring vegetation sampling at Ave 35 but was absent at Ave 67 at all sampling times. Stream water at B&M had high electrical conductivity (Table II).

### *Species richness*

*Plants*. The cumulative numbers of plant species sampled through time varied twofold among sites (Figure 2A). The accidentally restored urban reach (Price) had as many plant species as occurred at the reference reach (68 species each; Table III). Values were also high at one of the two urban restored sites (58 species at PRS). The fewest species (34) were at the driest site (Ave 67). For all sites collectively, 149 vascular plant taxa were sampled (Appendix 2).

Plot-level plant species richness varied by season ($F = 100{\cdot}6$, $df = 1$, $P < 0{\cdot}001$) and by site ($F = 14{\cdot}6$, $df = 6$, $P < 0{\cdot}001$) with significant interaction ($F = 12{\cdot}7$, $df = 6$, $P < 0{\cdot}001$). Most sites had substantially greater richness in March than in June or September, owing to seasonal establishment of rain-dependent winter annuals (Figure 3). Richness per plot was significantly greatest in two sites: the accidentally restored urban reach (Price) and the semi-restored urban reach (TRS).

*Birds*. We observed 108 species of birds along the Salt River during the study (Appendix 3). Similar to patterns for plants, cumulative bird species sampled varied twofold among sites (Figure 2B). Patterns for birds diverged in some ways from plants: the restored sites (B&M and PRS) and reference site

Table II. Stream flow, water salinity, and land cover type for seven reaches along the Salt River in central Arizona.

| | Stream flow permanence (%) | Electrical conductivity (ds/m) | Land cover-low flow channel and active floodplain | Land cover – terrace | Land cover – upland |
|---|---|---|---|---|---|
| Tonto | 100 | 1·25 ± 0·06 | Marsh, riparian forest | Riparian forest | Desert shrubland |
| Base and Meridian Wildlife Area | 100 | 2·56 ± 0·09 | Marsh, riparian forest (planted) | Desert shrubland and agriculture | Desert shrubland and agriculture |
| Phoenix Rio Salado | 99 | 0·88 ± 0·19 | Marsh, riparian forest | Riparian forest (planted) | Urban |
| Tempe Rio Salado | 100 | 1·29 ± 0·06 | Marsh, riparian forest (planted) | Urban | Urban |
| Price | 100 | 1·35 ± 0·04 | Marsh, riparian forest | Urban | Urban |
| Ave 35 | 6 | 1·54 | Riparian shrubland | Urban | Urban |
| Ave 67 | 7 | ND | Riparian shrubland | Urban | Urban |

Water quality values are means (±1 SE) across sampling seasons of 2012. Stream flow permanence is the percent of days in the year in which surface flow was present. ND, no data.

(Tonto) had significantly higher bird species richness compared with the semi-restored (TRS) and dry sites, both of which had lower species totals (Figure 2B; Table III). Ave 67, a dry reach, had significantly fewer species of birds than other sites (Figure 2B).

*Herpetofauna*. We recorded 11 species of amphibians and reptiles during surveys and observed three additional species near, but not within, a transect (Appendix 4). Cumulative numbers of amphibians and reptiles species sampled varied almost fourfold among sites (Figure 2C). The non-urban reference site (Tonto) had the greatest richness of herpetofauna, followed by the restored sites (B&M and PRS) (Figure 2C; Table III). The semi-restored site (TRS) had the lowest herpetofauna species richness.

### *Richness: wetland and desert affinity*

*Plants*. A noteworthy feature of the accidentally restored site (Price) was its high number of wetland plant species (26). In comparison, 17 and 18 were present at the actively restored sites, and 11 were at the reference site (Table III; Figure 3). Some wetland species, including *Samolus parviflorus* and *Stemodia durantifolia*, were sampled only at Price. *Eustoma exaltatum* was found only at Price and TRS.

The non-urban reference site differed notably from others in having a high number (42) of xerophytes, many of which were spring annuals not found elsewhere (e.g. *Plagiobothrys arizonicus* and *Chaenactis stevioides*). Number of xerophytes ranged from 15 to 26 among all other sites. Mesophytes ranged from nine to 15 species among sites.

*Birds*. The restored (B&M and PRS) and non-urban reference sites had high richness of riparian bird species (Table III). Some of these riparian species, such as brown-crested flycatcher (*Myiarchus tyrannulus*), Lucy's Warbler (*Oreothlypis luciae*), and Bell's Vireo (*Vireo bellii*), were recorded only at the reference site, whereas other species such as Warbling Vireo (*Vireo gilvus*) were recorded only at restored sites. Riparian species richness was lowest at the dry sites (Table III). The restored and semi-restored sites (B&M, PRS, and TRS) and accidentally restored site (Price) had high richness of aquatic and marshland birds species (Table III). The high richness of aquatic and marshland species at the dry site (Ave 35) was due to Northern Pintails (*Anas acuta*) detected when the stream was wet during the winter survey.

The non-urban reference site was noteworthy in having more desert-affiliated bird species than any other site (Table III). For example, the reference site was the only location where desert species such as Cactus Wrens (*Campylorhynchus brunneicapillus*) and nearly all curve-billed thrashers (*Toxostoma curvirostre*) were detected. Surprisingly, the dry sites had low number of desert species but did harbour some desert-adapted birds such as loggerhead shrikes (*Lanius ludovicianus*).

*Herpetofauna*. Amphibians (mostly toads, *Anaxyrus* spp.), a water-affiliated group, were recorded in transects only at the reference site, one restored site (PRS), and one dry site (Ave 35). However, we observed or heard calls from introduced American bullfrogs (*Lithobates catesbeianus*) at all sites with perennial water flows (i.e. reference, restored, and accidentally restored).

We documented the semi-arboreal desert spiny lizard (*Sceloporus magister*) at the reference site and mixed-use, restored site (B&M). Although not detected within a survey plot, we documented desert iguanas (*Dipsosaurus dorsalis*), a desert specialist, at the dry reaches and in drier portions of the reference site.

### *Abundance*

*Plants*. Plant cover varied by site ($F = 14{\cdot}7$, $df = 6$, $P = <0{\cdot}001$) but not by season, with significant interaction ($F = 10{\cdot}2$, $df = 6$, $P < 0{\cdot}001$). The dry sites and mixed-use

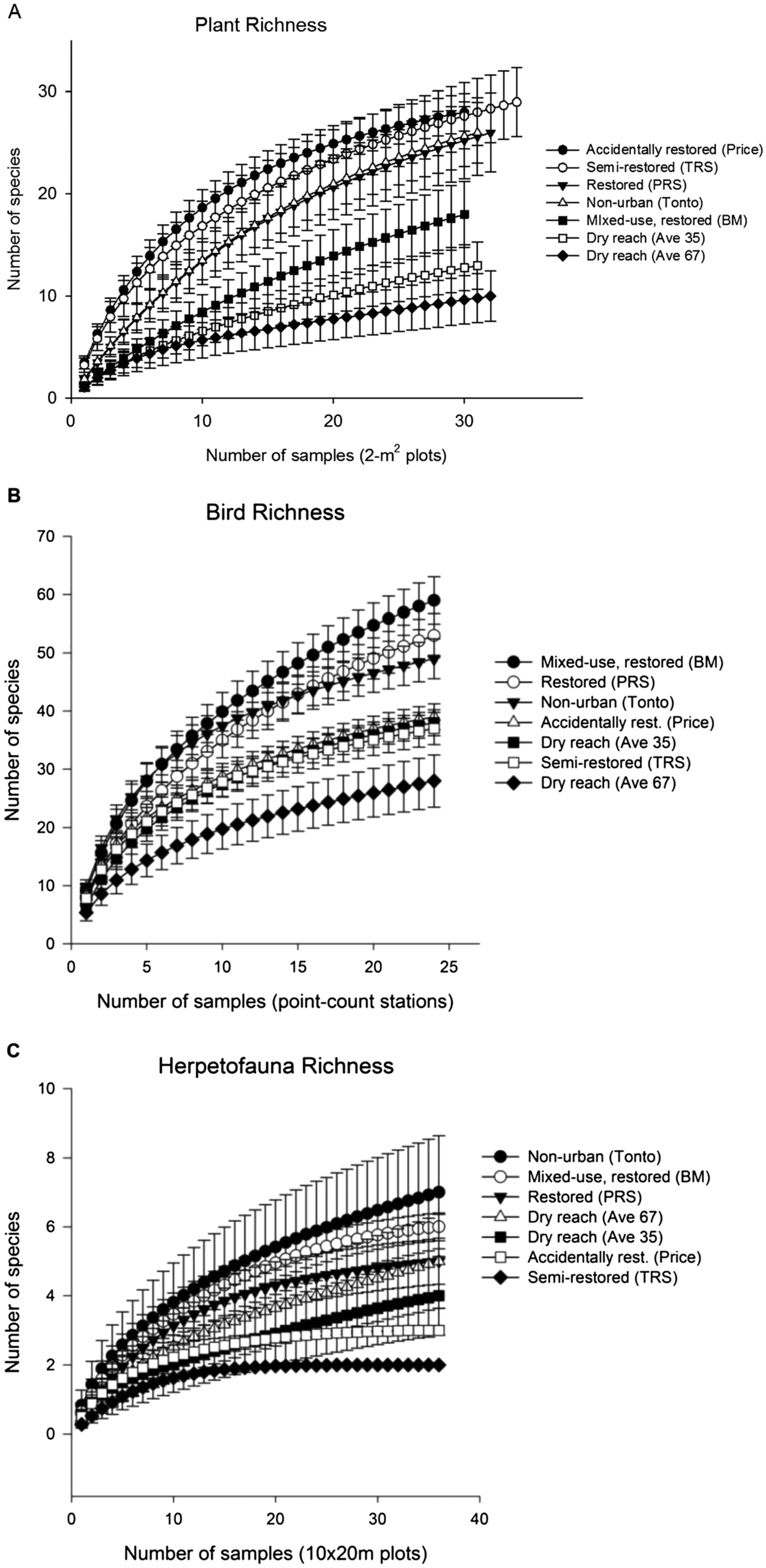

Figure 2. Species accumulation curves for (A) vascular plants, (B) bird species, and (C) herpetofauna species along the Salt River in central Arizona. Plants were surveyed during the pre-monsoon dry season. Birds and herpetofauna were surveyed during warm seasons (March to September).

Table III. Species richness of plant and animal taxa at seven reaches along the Salt River in central Arizona.

| | Plant richness | | | | | Bird richness | | | | | | Herpetofauna richness | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Aquatic | Hydric | Mesic | Xeric | Total | Aquatic, marshland | Riparian terrestrial | Desert | Urban, general | Other | Total | Aquatic (amphib) | Terrestrial (reptiles) |
| Tonto | 68 | 6 | 11 | 9 | 42 | 50 | 11 | 12 | 13 | 7 | 7 | 7 | 1 | 6 |
| Base and Meridian Wildlife Area | 42 | 1 | 10 | 12 | 19 | 62 | 15 | 13 | 10 | 10 | 14 | 6 | 0 | 6 |
| Phoenix Rio Salado | 58 | 0 | 17 | 15 | 26 | 55 | 15 | 11 | 7 | 13 | 9 | 6 | 2 | 4 |
| Tempe Rio Salado | 42 | 1 | 18 | 8 | 15 | 39 | 9 | 8 | 6 | 12 | 4 | 2 | 0 | 2 |
| Price | 68 | 3 | 26 | 15 | 24 | 42 | 16 | 7 | 6 | 9 | 4 | 4 | 1 | 3 |
| Ave 35 | 44 | 0 | 7 | 14 | 23 | 43 | 17 | 5 | 4 | 9 | 8 | 5 | 1 | 4 |
| Ave 67 | 34 | 0 | 4 | 9 | 21 | 31 | 6 | 4 | 6 | 9 | 6 | 4 | 0 | 4 |

Values are cumulative totals across sampling seasons.

restoration site had sparse cover. The urban restored (PRS), semi-restored (TRS), and accidentally restored (Price) sites all had very high cover (Figure 3; Table IV).

Sites differed in the distribution of cover among plant moisture groups. Cover of wetland plants (including the emergents *Eleocharis geniculata*, *Ludwigia peploides*, *Schoenoplectus acutus*, and *Typha domingensis* and the tree *S. gooddingii*) was greatest at the semi-restored (TRS) site with values also high at the restored (PRS) accidentally restored (Price) sites. Other common species at these sites were *Cynodon dactylon* and *Tamarix ramosissima*. Wetland plants were restricted to a narrow zone along the water's edge of the reference site, with mesophytes (e.g. *C. dactylon* and *P. velutina*) and xerophytes (e.g. *Baccharis sarothroides* and *Ambrosia monogyra*) being the most common plant types. The sparse cover of the mixed-use restored site (B&M) was composed mainly of wetland plants along the water's edge (e.g. *L. peploides*) and haloxerophytes (e.g. *Atriplex lentiformis*) in the open and saline floodplain. Pioneer xerophytes including the shrubs *Bebbia juncea* and *Ambrosia eriocentra* provided the dominant cover at dry sites. *Typha* marshlands were present at Ave 35 during spring, but the wetland plants died with onset of the hot and dry summer.

*Birds*. Total bird abundance was consistent across seasons ($F = 0{\cdot}530$, df = 1, $P = 0{\cdot}479$) but varied by site ($F = 3{\cdot}160$, df = 6, $P = 0{\cdot}036$). Only two sites differed in abundance (B&M, mean = 30·1 ± 3·5 SE; Ave 67, mean = 10·3, ±3·5 SE; $P = 0{\cdot}019$). There was no season by site interaction ($F = 1{\cdot}464$, df = 6, $P = 0{\cdot}260$). However, there were differences in bird abundance per guild (Table IV). Riparian terrestrial bird abundance was similar in spring and summer ($F = 1{\cdot}400$, df = 1, $P = 0{\cdot}256$), differed by site ($F = 5{\cdot}977$, df = 6, $P = 0{\cdot}003$; Figure 4A), with an interaction ($F = 5{\cdot}933$, df = 6, $P = 0{\cdot}003$). The greatest difference among reach types was between the accidentally restored (Price) and dry urban sites ($P < 0{\cdot}01$), and between the non-urban site (Tonto) and dry sites ($P = 0{\cdot}06$) with the dry sites having the lowest riparian bird abundance.

All reaches had a mix of aquatic/marsh, riparian, desert, and urban-generalist birds (Tables III and IV). Desert species (such as Abert's towhees, *Pipilo aberti*, and white-winged doves, *Zenaida asiatica*) were abundant at all reaches except the dry reaches and were particularly common at one of the accidentally restored sites. Aquatic and marshland birds (such as waterfowl and red-winged blackbird, *Agelaius phoeniceus*) were most abundant at actively and accidentally restored sites. Habitat generalists and species tied to human habitation and structures, such as mourning doves (*Zenaida macroura*) and house finches (*Carpodacus mexicanus*), were common across river reach types but were most abundant in dry reaches.

*Herpetofauna*. Herpetofauna abundance differed by season ($F = 27{\cdot}562$, df = 1, $P < 0{\cdot}001$) but not by site ($F = 1{\cdot}492$,

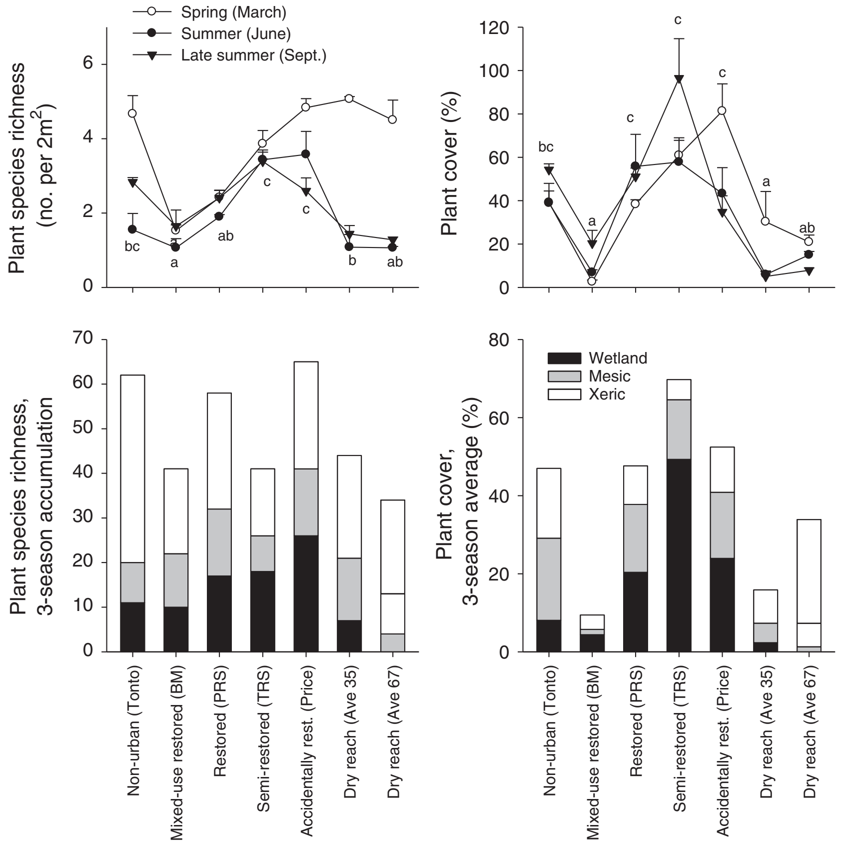

Figure 3. Plant cover for sites along the Salt River. The top panel shows means ± 1 SE for plot-level richness and cover data collected in three sampling seasons. The bottom panel shows site-level values (30 plots) accumulated over three seasons (species richness) or averaged for three seasons (cover) and categorized by plant moisture class.

df = 6, $P = 0{\cdot}251$). However, there was a significant season by site interaction ($F = 3{\cdot}026$, df = 6, $P = 0{\cdot}041$; Figure 4B). The most numerous species was common side-blotched lizard (*Uta stansburiana*), present at all sites. We also detected tiger whiptail (*Aspidoscelis tigris*) at all sites. Both of these species have broad habitat requirements.

### *Ordination analysis*

*Plants*. The distribution of sites in ordination space was related to stream flow permanence and urbanization. Dry sites formed discrete clusters from wetter sites along NMDS axis 1 (Figure 5A; flow, $P = 0{\cdot}001$). The environmental vector representing an urban component showed sites separating along NMDS axis 3 (Figure 5B; urban $P = 0{\cdot}01$). The PRS site clustered closely in ordination space with TRS as did the reference site (Tonto) with the accidentally restored site (Price; Figure 5A). The mixed-use restored site (B&M) formed its own discrete cluster. The NMDS analysis for plants had a stress level of 8·43% with three dimensions and a linear fit $R^2$ of 93·7 (Bray distance, square root and Wisconsin transformations, Oksanen *et al.*, 2013).

*Birds*. The NMDS for the bird community indicated that a three-dimensional solution best fit the data (stress = 12·64%, linear fit $R^2 = 86{\cdot}3$, Bray distance, square root transformation, Oksanen *et al.*, 2013; Figure 6A and B). NMDS axis 1 best described seasonal differences in the bird communities, with migratory waterfowl abundant during winter (i.e. northern shoveler, *Anas clypeata*; bufflehead, *Bucephala albeola*; gadwall, *Anas strepera*; and pied-billed grebe, *Podilymbus podiceps*; Figure 6A). NMDS axis 2 revealed structuring among the bird communities by the environmental vector representing flow with dry sites forming clusters from wetter sites (Figure 6B; flow $P < 0{\cdot}001$). The non-urban reference (Tonto), restored (PRS), and accidentally restored (Price) sites clustered closely in ordination space (Figure 6B). Consistent with bird abundance results, the bird community of dry reaches had more species associated with human infrastructure (i.e. house sparrow, *Passer domesticus*; northern mockingbird, *Mimus polyglottos*; house finch, *C. mexicanus*; and mourning dove, *Z. macroura*). The bird community of the reference reach had greater numbers of specialist species such as riparian-associated species (brown-crested flycatcher, *M. tyrannulus*; yellow warbler, *Setophaga petechia*; and Lucy's warbler, *O. luciae*) and desert-associated species (ladder-backed woodpecker, *Picoides scalaris*, and phainopepla, *Phainopepla nitens*). Accidentally restored and actively restored sites had

Table IV. Total cover or abundance of plants and animals, and relative abundance by category, at seven reaches along the Salt River in central Arizona.

| | Plant cover (three-season average) | | | | Bird abundance | | | | | | Herpetofauna abundance | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Hydric (%) | Mesic (%) | Xeric (%) | Total | Aquatic, marshland (%) | Riparian terrestrial (%) | Desert (%) | Urban, general (%) | Other (%) | Total | Aquatic (amphib) (%) | Terrestrial (reptiles) (%) |
| Tonto | 47 | 17 | 45 | 38 | 502 | 12 | 8 | 33 | 41 | 6 | 25 | 1 | 99 |
| Base and Meridian Wildlife Area | 9 | 46 | 14 | 39 | 605 | 14 | 23 | 14 | 40 | 10 | 38 | 0 | 100 |
| Phoenix Rio Salado | 48 | 43 | 37 | 21 | 413 | 23 | 10 | 27 | 32 | 7 | 44 | 7 | 93 |
| Tempe Rio Salado | 70 | 71 | 22 | 7 | 456 | 14 | 16 | 25 | 44 | 1 | 30 | 0 | 100 |
| Price | 52 | 46 | 32 | 22 | 663 | 14 | 18 | 43 | 23 | 1 | 42 | 2 | 98 |
| Ave 35 | 16 | 15 | 32 | 54 | 523 | 6 | 23 | 5 | 46 | 19 | 16 | 4 | 96 |
| Ave 67 | 23 | 4 | 18 | 78 | 437 | 6 | 8 | 5 | 76 | 5 | 49 | 0 | 100 |

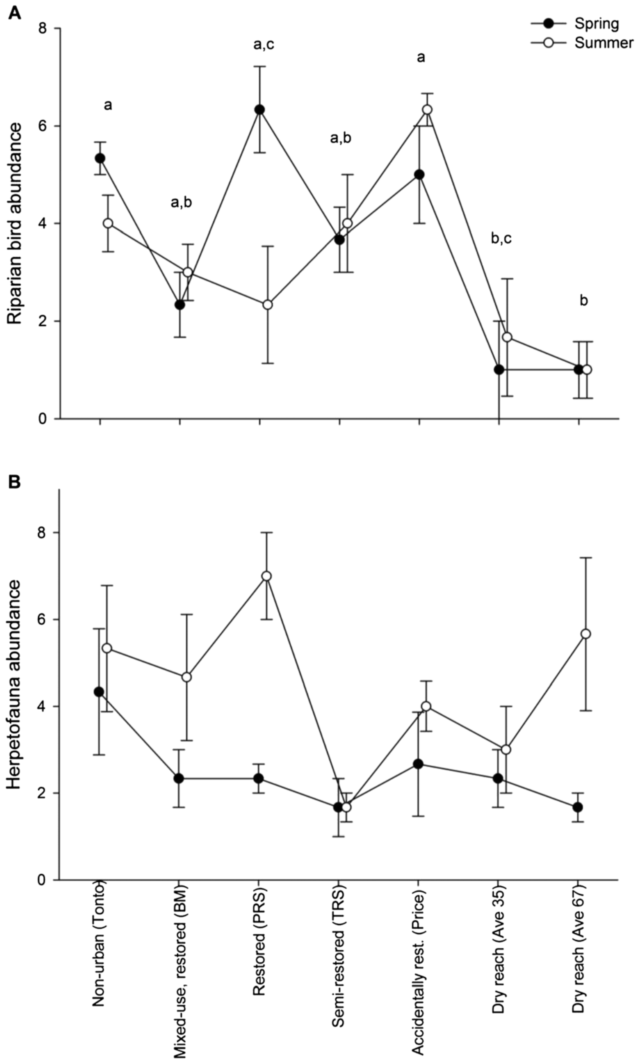

Figure 4. Abundance of (A) riparian birds and (B) abundance of amphibian and reptile species (herpetofauna) during spring and summer seasons sampled among seven river reaches. Both taxa abundance varied by season and bird abundance varied by site (indicated by letters).

the greatest overlap, reflecting underlying similarity in bird community composition.

*Herpetofauna*. The NMDS for herpetofauna indicated that a three-dimensional solution best fit the data (stress = 8·31%, linear fit $R^2 = 95{\cdot}3$, Bray distance, Wisconsin transformation, Oksanen *et al.*, 2013; Figure 7). Habitat generalist species (tiger whiptails and common side-blotched lizards) were more associated with the urbanization gradient (Figure 7). The reference reach spans a continuum from wet stream edge to riparian terrace/desert upland and thus has wide spread on NMDS axis 1. Along NMDS axis 2, urban sites such as the restored (PRS), semi-restored (TRS), and accidentally restored (Price) sites cluster together and are dissimilar to the non-urban reference site.

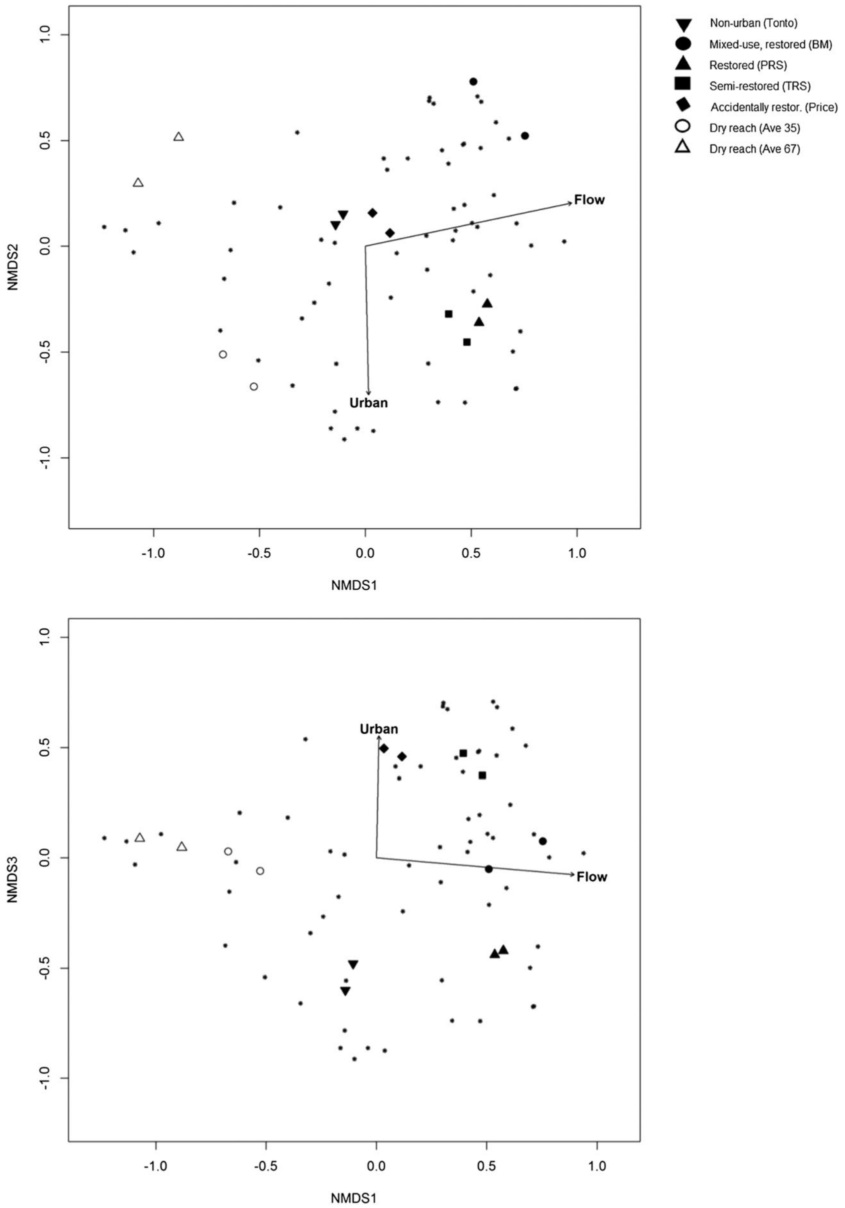

Figure 5. Non-metric multidimensional scaling (NMDS) graph showing locations of seven vegetation sampling sites in each of two seasons (July and September). (A) NMDS axis 1 separates plant species (small dots) by flow permanence, and (B) NMDS axes 2 and 3 separate species by degree of urbanization.

## DISCUSSION

Our multi-taxa approach provides an assessment of how urban riparian biotic communities compare among reaches that have been actively restored via planting and irrigation and those that have been accidentally restored by passive discharge of novel urban sources of water sufficient to create perennial stream flows. One major conclusion is that passive urban discharge along arid urban streams can provide the hydrologic conditions needed for establishing critical wetland and riparian habitat without other types of intervention or management. Importantly, the accidentally restored areas maintain a subset of the riparian-wetland complex – freshwater marshes – that is, perhaps in the greatest need of regional restoration. Weisberg *et al.* (2013) note that riparian herbaceous wetlands have declined dramatically in the desert Southwest and have advocated for restoration of diverse and dynamic mosaics, including marshlands, as an alternative to a single-minded focus on tree establishment. Urbanization of the Salt River has inadvertently allowed for development of intermixed marshlands and riparian forests via the discharge of effluent and stormwater from outfalls that drain large urban catchments with extensive impermeable surfaces; these surface waters are confined within a comparatively deep and narrow cobble and silt-lined stream channel. Although the suite of plants at the rewatered sites colonize via multiple dispersal mechanisms

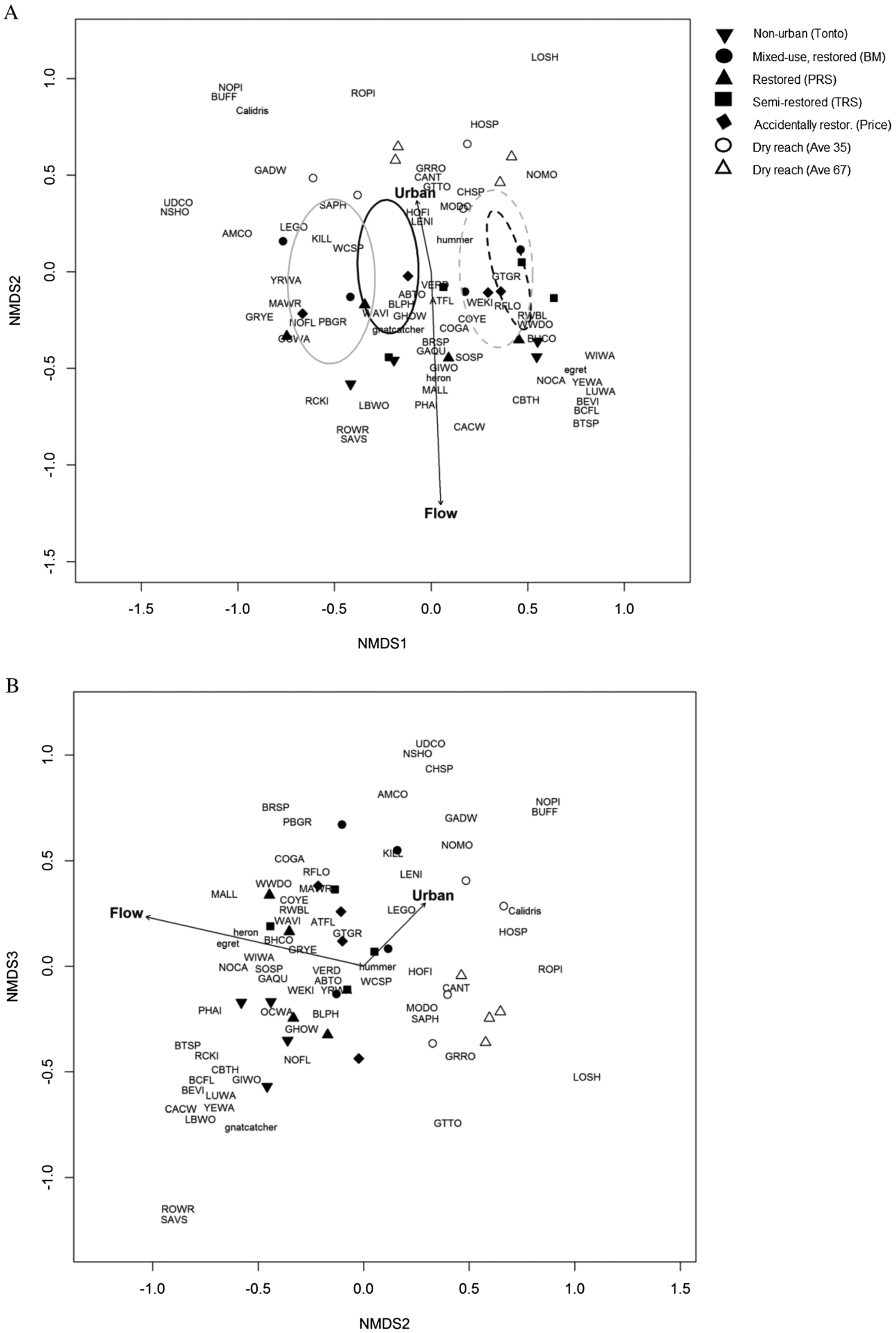

Figure 6. Non-metric multidimensional scaling (NMDS and SE ellipses) graphs for bird species (plotted as four-letter codes; Appendix 3) sampled among seven river reaches. (A) NMDS axis 1 separates bird species by season, with most waterfowl and marshland birds being abundant during winter (ellipses: fall is black, winter is grey, spring is grey dotted, and summer is black dotted). (B) NMDS axis 2 separates bird community by amount of flow, with urban dry sites most dissimilar to other reaches.

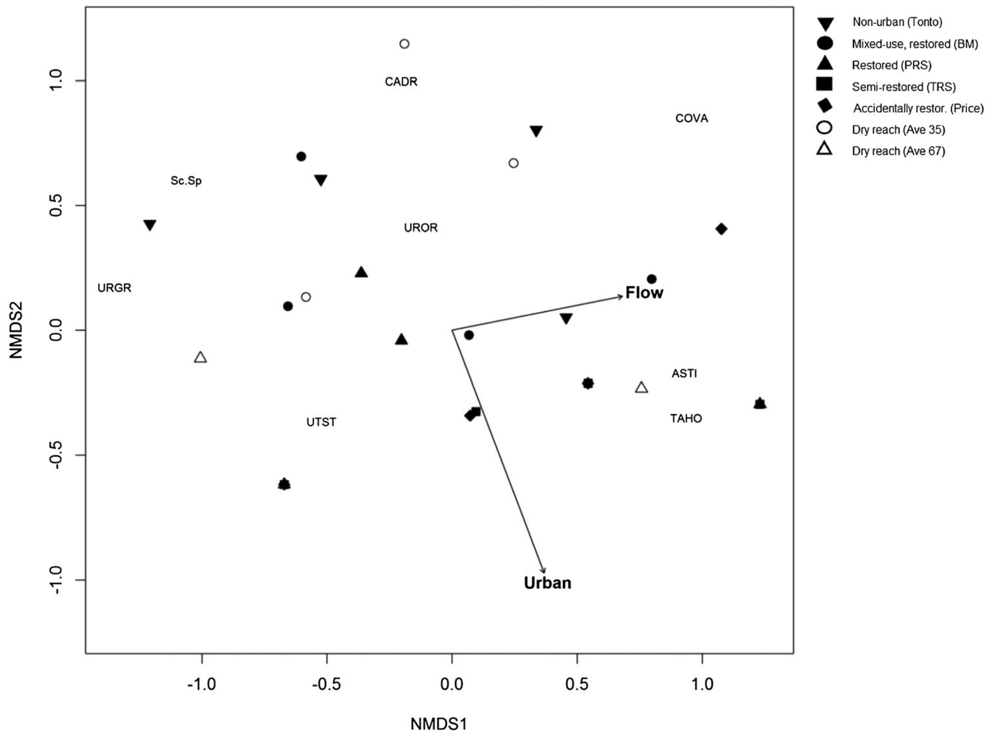

Figure 7. Non-metric multidimensional scaling (NMDS) graph for herpetofauna species (plotted as four-letter codes; Appendix 4) sampled among seven river reaches.

(wind, animals, and water), near-surface water availability is critical to long-term survival, underscoring the importance of effluent and stormwater runoff as a restoration water source (Stromberg *et al*., 2009; Kehr *et al*., 2014). Providing means to secure these novel water sources and protect these freshwater habitats will benefit many species including migratory birds and herpetofauna (Trammell *et al*., 2011; Scheffers and Paszkowski, 2013).

Another conclusion is that accidental and active restoration can serve as complementary approaches to river management. The actively restored reaches (B&M and PRS) differed from the accidentally restored (Price) areas in having greater richness of birds and herpetofauna (including arboreal reptiles), patterns that reflected the direct planting and irrigation of riparian trees. More generally, although many individual restoration projects fall short of their goals (Benayas *et al*., 2009; Violin *et al*., 2011), restoration may be successful when viewed through a larger lens. Although heavily engineered urban streams such as the Salt River often have low habitat diversity at any particular location, the presence of a range of stream conditions and management approaches over a river length can increase habitat diversity at the landscape scale (Gurnell *et al*., 2012). Collectively, the actively restored and accidentally restored sites, as well as dry reaches, are contributing to a diverse riparian and wetland mosaic along the urbanized Salt River including pioneer riparian gallery forests and shrublands, marshlands, and xeroriparian pioneer shrublands with desert-adapted wildlife. These results are similar to those of Aronson *et al.* (2014) who investigated plant and bird richness in 147 international cities and found that many species (a high percentage of which were native) do occupy urban habitats.

However, the reference reach differs in some significant ways from the urban reaches. It supported unique bird and plant species, the greatest herpetofauna species richness, and high total numbers of plant species. It also sustained a wide swath of mature *Prosopis* forests on high floodplains and river terraces (Haase, 1972). These patterns occurred because, unlike the channelized urbanized river sections, this reach retains lateral connectivity with the desert uplands. This finding can provide guidance for future restoration measures in the urban setting.

Consideration of seasonal changes of biodiversity is another important element in riparian management. Conservation and restoration of freshwater habitats must account for annual cycles and habitat use of terrestrial, riparian, and aquatic species (Dudgeon *et al*., 2006). For example, we found that waterfowl and marshland birds used urban reaches to a greater extent during the winter, which is a time when many species overwinter in southern latitudes. With respect to plants, one guild of the riparian-zone plant community, cool-season annuals, was unexpectedly sparse at the restored reaches (and abundant elsewhere). This may have been a result of the soil bulldozing and disruption of soil seed banks that occurred during the active restoration phase. The seeds of such species do provide an important food source for many birds and mammals.

One major challenge facing aridland riparian systems will be managing both climate change and urban population growth. Climate change models show that, in general, relatively dry subtropical regions such as the American Southwest will experience a decrease in precipitation and become hotter (Seager *et al*., 2007). In Arizona specifically, surface runoff, lateral flow, soil water, and groundwater recharge are expected to decrease significantly with some watershed discharges projected to decrease by 47% in the 2050s (Ye and Grimm, 2013). The combination of reduced available water supplies and increases in water demand will intensify the competition between human and ecological uses for water (Hall *et al*., 2008; Loaiciga, 2009). Our results underscore the importance of utilizing novel sources of water to preserve freshwater habitats along arid urban streams.

## ACKNOWLEDGEMENTS

For providing access to sites or information about sites, we thank the Arizona Game and Fish Department, City of Phoenix, City of Tempe, USDA Tonto National Forest Service, and Maricopa County Flood Control District. For assistance with field work, we thank Robert Madera, Rebecca DePuydt, Andy Bridges, Beau Rudd, and Justin Poulter. We thank the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) for providing funding (NSF BCS-1026865).

## APPENDIX

APPENDIX 1. Photographs from seven reaches along the Salt River in central Arizona. Photo descriptions list reach type, location name, number in reference to Figure 1, elevation, and coordinates in latitude and longitude. Photos taken by M. Banville, except non-urban reference taken by E. Makings.

Non-urban reference site, Tonto National Forest, Map #1, 412 m, 33·558948°, -111·958754°

Restored Phoenix Rio Salado (PRS) Area, Map #4, 323 m, 33·422419°, -112·075205°

Mixed-use, restored Base and Meridian Wildlife Area (B&M), Map #7, 286 m, 33.384375°, -112˙303177°

Accidentally restored, Price Drain (Price), Map #2, 360 m, 33·437428°, -111·887722°

Semi-restored Tempe Rio Salado (TRS), Map #3, 347 m, 33·434910°, -111·958754°

Dry reach, 35th Avenue (Ave 35), Map #5, 312 m, 33·411469°, -112·133450°

Dry reach, 67th Avenue (Ave 67), Map #6, 300 m, 33·395838, -112·204064

APPENDIX 2. Species list for plants sampled in quadrats along the Salt River in central Arizona. Sites included urban reaches and a non-urban reference site.

| Scientific name | Family |
|---|---|
| *Acacia constricta* | Fabaceae |
| *Acacia greggii* | Fabaceae |
| *Acacia stenophylla* | Fabaceae |
| *Amaranthus albus* | Amaranthaceae |
| *Ambrosia ambrosioides* | Asteraceae |
| *Ambrosia eriocentra* | Asteraceae |
| *Amsinckia menziesii var. intermedia* | Boraginaceae |
| *Aristida purpurea* | Poaceae |
| *Atriplex elegans* | Amaranthaceae |
| *Atriplex lentiformis* | Amaranthaceae |
| *Atriplex polycarpa* | Amaranthaceae |
| *Azolla filiculoides* | Azollaceae |
| *Baccharis salicifolia* | Asteraceae |
| *Baccharis sarothroides* | Asteraceae |
| *Bebbia juncea* | Asteraceae |
| *Boerhavia coccinea* | Nyctaginaceae |
| *Boerhavia coulteri* | Nyctaginaceae |
| *Boerhavia erecta* | Nyctaginaceae |
| *Bouteloua aristidoides* | Poaceae |
| *Bouteloua curtipendula* | Poaceae |
| *Brassica tournefortii* | Brassicaceae |
| *Bromus rubens* | Poaceae |
| *Calandrinia ciliata* | Portulacaceae |
| *Calibrachoa parviflora* | Solanaceae |
| *Camissonia californica* | Onagraceae |
| *Ceratophyllum demersum* | Ceratophyllaceae |
| *Chaenactis stevioides* | Asteraceae |
| *Euphorbia albomarginata* | Euphorbiaceae |
| *Euphorbia hyssopifolia* | Euphorbiaceae |

(Continues)

Appendix 2. (Continued)

| | |
|---|---|
| *Euphorbia maculata* | Euphorbiaceae |
| *Euphorbia micromera* | Euphorbiaceae |
| *Euphorbia polycarpa var. hirtella* | Euphorbiaceae |
| *Chenopodium berlandieri* | Amaranthaceae |
| *Chilopsis linearis* | Bignoniaceae |
| *Chorizanthe brevicornu* | Polygonaceae |
| *Cotula australis* | Asteraceae |
| *Crassula connata* | Crassulaceae |
| *Cryptantha angustifolia* | Boraginaceae |
| *Cryptantha barbigera* | Boraginaceae |
| *Cryptantha decipiens* | Boraginaceae |
| *Cryptantha maritima* | Boraginaceae |
| *Cryptantha muricata* | Boraginaceae |
| *Cylindropuntia fulgida* | Cactaceae |
| *Cynodon dactylon* | Poaceae |
| *Cyperus elegans* | Cyperaceae |
| *Cyperus eragrostis* | Cyperaceae |
| *Cyperus involucratus* | Cyperaceae |
| *Cyperus odoratus* | Cyperaceae |
| *Cyperus oxylepis* | Cyperaceae |
| *Datura wrightii* | Solanaceae |
| *Dicoria canescens* | Asteraceae |
| *Distichlis spicata* | Poaceae |
| *Echinochloa crus-galli* | Poaceae |
| *Eclipta prostrata* | Asteraceae |
| *Eleocharis geniculata* | Cyperaceae |
| *Encelia farinosa* | Asteraceae |
| *Eriogonum deflexum* | Polygonaceae |
| *Erodium cicutarium* | Geraniaceae |
| *Eustoma exaltatum* | Gentianaceae |
| *Funastrum cynanchoides ssp. heterophyllum* | Apocynaceae |
| *Gilia sp.* | Polemoniaceae |
| *Hedypnois cretica* | Asteraceae |
| *Heliotropium curassavicum* | Boraginaceae |
| *Herniaria hirsuta* | Caryophyllaceae |
| *Heterotheca subaxillaris* | Asteraceae |
| *Hordeum murinum* | Poaceae |
| *Hydrocotyle verticillata* | Apiaceae |
| *Hymenoclea monogyra* | Asteraceae |
| *Hymenoclea salsola* | Asteraceae |
| *Lactuca serriola* | Asteraceae |
| *Larrea tridentata* | Zygophyllaceae |
| *Lemna sp.* | Araceae |
| *Lepidium lasiocarpum* | Brassicaceae |
| *Lepidium virginicum* | Brassicaceae |
| *Leptochloa fusca ssp. uninervia* | Poaceae |
| *Logfia arizonica* | Asteraceae |
| *Ludwigia peploides* | Onagraceae |
| *Lycium andersonii* | Solanaceae |
| *Lythrum californicum* | Lythraceae |
| *Malva parviflora* | Malvaceae |
| *Melilotus indica* | Fabaceae |
| *Mentzelia albicaulis* | Loasaceae |
| *Najas marina* | Najadaceae |
| *Nicotiana obtusifolia* | Solanaceae |
| *Oncosiphon piluliferum* | Asteraceae |
| *Opuntia sp.* | Cactaceae |
| *Parkinsonia aculeata* | Fabaceae |
| *Parkinsonia florida* | Fabaceae |
| *Pectocarya heterocarpa* | Boraginaceae |

*(Continues)*

Appendix 2. (Continued)

| | |
|---|---|
| *Pectocarya platycarpa* | Boraginaceae |
| *Pectocarya recurvata* | Boraginaceae |
| *Pennisetum ciliare* | Poaceae |
| *Pennisetum setaceum* | Poaceae |
| *Phacelia crenulata var. ambigua* | Hydrophyllaceae |
| *Phalaris minor* | Poaceae |
| *Phoradendron californicum* | Santalaceae |
| *Arundo donax* | Poaceae |
| *Plagiobothrys arizonicus* | Boraginaceae |
| *Plantago ovata* | Plantaginaceae |
| *Pluchea odorata* | Asteraceae |
| *Pluchea sericea* | Asteraceae |
| *Polanisia dodecandra* | Capparaceae |
| *Polygonum aviculare* | Polygonaceae |
| *Persicaria bicornis* | Polygonaceae |
| *Polygonum persicaria* | Polygonaceae |
| *Polypogon monspeliensis* | Poaceae |
| *Populus fremontii* | Salicaceae |
| *Portulaca oleracea* | Portulacaceae |
| *Potamogeton sp.* | Potamogetonaceae |
| *Prosopis chilensis* | Fabaceae |
| *Prosopis pubescens* | Fabaceae |
| *Prosopis velutina* | Fabaceae |
| *Pseudognaphalium luteoalbum* | Asteraceae |
| *Pseudognaphalium stramineum* | Asteraceae |
| *Ricinus communis* | Euphorbiaceae |
| *Rumex dentatus* | Polygonaceae |
| *Salix gooddingii* | Salicaceae |
| *Salsola kali* | Amaranthaceae |
| *Samolus parviflorus* | Primulaceae |
| *Schismus arabicus* | Poaceae |
| *Schoenoplectus acutus* | Cyperaceae |
| *Senna covesii* | Fabaceae |
| *Sesbania herbacea* | Fabacaeae |
| *Sesuvium verrucosum* | Aizoaceae |
| *Sisymbrium irio* | Brassicaceae |
| *Solanum elaeagnifolium* | Solanaceae |
| *Sonchus asper* | Asteraceae |
| *Sonchus oleraceus* | Asteraceae |
| *Sorghum halepense* | Poaceae |
| *Sporobolus airoides* | Poaceae |
| *Sporobolus sp.* | Poaceae |
| *Sporobolus wrightii* | Poaceae |
| *Stemodia durantifolia* | Plantaginaceae |
| *Stephanomeria pauciflora* | Asteraceae |
| *Stuckenia sp.* | Potamogetonaceae |
| *Stylocline micropoides* | Asteraceae |
| *Symphyotrichum expansum* | Asteraceae |
| *Tamarix ramosissima* | Tamaricaceae |
| *Tidestromia lanuginosa* | Amaranthaceae |
| *Trianthema portulacastrum* | Aizoaceae |
| *Tribulus terrestris* | Zygophyllaceae |
| *Triticum aestivum* | Poaceae |
| *Typha domingensis* | Typhaceae |
| *Veronica anagallis-aquatica* | Plantaginaceae |
| *Vitex agnus-castus* | Verbenaceae |
| *Vulpia octoflora* | Poaceae |
| *Washingtonia filifera* | Arecaceae |
| *Xanthium strumarium* | Asteraceae |
| *Zannichellia palustris* | Potamogetonaceae |

*(Continues)*

APPENDIX 3. Species list for birds seen along the Salt River in central Arizona. Bird species are categorized by major habitat type. Riparian (R) species are terrestrial birds associated (not obligate) with floodplain vegetation (e.g. cottonwood, willow, and mesquite). Aquatic (W) species are birds associated with marshlands or bodies of water (such as waders, ducks, and herons). Desert (D) birds are species associated with shrubs and cacti of the Sonoran Desert. Urban (U) species are habitat generalists or associated with human habitation and structures (such as exotic perching birds, swallows, and grackle).

| Species codes | Common name | Scientific name | Group | Exotic |
|---|---|---|---|---|
| ABTO | Abert’s towhee | *Melozone aberti* | D | |
| AMCO | American coot | *Fulica americana* | W | |
| AMKE | American kestrel | *Falco sparverius* | | |
| ANHU | Anna’s hummingbird | *Calypte anna* | R | |
| ATFL | Ash-throated flycatcher | *Myiarchus cinerascens* | R | |
| AWPE | American white pelican | *Pelecanus erythrorhynchos* | W | |
| BAEA | Bald eagle | *Haliaeetus leucocephalus* | W | |
| BARS | Barn swallow | *Hirundo rustica* | U | |
| BCFL | Brown-crested flycatcher | *Myiarchus tyrannulus* | D | |
| BCHU | Black-chinned hummingbird | *Archilochus alexandri* | R | |
| BCNH | Black-crowned night heron | *Nycticorax nycticorax* | W | |
| BEKI | Belted kingfisher | *Megaceryle alcyon* | W | |
| BETH | Bendire’s thrasher | *Toxostoma bendirei* | D | |
| BEVI | Bell’s vireo | *Vireo bellii* | R | |
| BHCO | Brown-headed cowbird | *Molothrus ater* | U | |
| BLGR | Blue grosbeak | *Passerina caerulea* | R | |
| BLPH | Black phoebe | *Sayornis nigricans* | W | |
| BLVU | Black vulture | *Coragyps atratus* | | |
| BNST | Black-necked stilt | *Himantopus mexicanus* | W | |
| BRBL | Brewer’s blackbird | *Euphagus cyanocephalus* | | |
| BRSP | Brewer’s sparrow | *Spizella breweri* | | |
| BTGN | Black-tailed gnatcatcher | *Polioptila melanura* | D | |
| BTSP | Black-throated sparrow | *Amphispiza bilineata* | D | |
| BUFF | Bufflehead | *Bucephala albeola* | W | |
| CACW | Cactus wren | *Campylorhynchus brunneicapillus* | D | |
| CANT | Canyon towhee | *Melozone fusca* | D | |
| CANV | Canvasback | *Aythya valisineria* | W | |
| CBTH | Curve-billed thrasher | *Toxostoma curvirostre* | D | |
| CHSP | Chipping sparrow | *Spizella passerina* | | |
| CLSW | Cliff swallow | *Petrochelidon pyrrhonota* | U | |
| COGA | Common gallinule | *Gallinula galeata* | W | |
| COHA | Cooper’s hawk | *Accipiter cooperii* | | |
| COME | Common merganser | *Mergus merganser* | W | |
| CORA | Common raven | *Corvus corax* | | |
| COYE | Common yellowthroat | *Geothlypis trichas* | R | |
| DCCO | Double-crested cormorant | *Phalacrocorax auritus* | W | |
| EUCD | Eurasian collared-dove | *Streptopelia decaocto* | U | E |
| EUST | European starling | *Sturnus vulgaris* | U | E |
| GADW | Gadwall | *Anas strepera* | W | |
| GAQU | Gambel’s quail | *Callipepla gambelii* | D | |
| GBHE | Great blue heron | *Ardea herodias* | W | |
| GHOW | Great horned owl | *Bubo virginianus* | | |
| GIWO | Gila woodpecker | *Melanerpes uropygialis* | D | |
| GREG | Great egret | *Ardea alba* | W | |
| GRHE | Green heron | *Butorides virescens* | W | |
| GRRO | Greater roadrunner | *Geococcyx californianus* | D | |
| GRYE | Greater yellowlegs | *Tringa melanoleuca* | W | |
| GTGR | Great-tailed grackle | *Quiscalus mexicanus* | U | |
| GTTO | Green-tailed towhee | *Pipilo chlorurus* | | |
| HOFI | House finch | *Carpodacus mexicanus* | U | |
| HOOR | Hooded oriole | *Icterus cucullatus* | R | |
| HOSP | House sparrow | *Passer domesticus* | U | E |
| INDO | Inca dove | *Columbina inca* | U | |
| KILL | Killdeer | *Charadrius vociferus* | W | |

*(Continues)*

Appendix 3. (Continued)

| Species codes | Common name | Scientific name | Group | Exotic |
|---|---|---|---|---|
| LASP | Lark sparrow | *Chondestes grammacus* | | |
| LBWO | Ladder-backed woodpecker | *Picoides scalaris* | D | |
| LEGO | Lesser goldfinch | *Spinus psaltria* | R | |
| LENI | Lesser nighthawk | *Chordeiles acutipennis* | | |
| LESA | Least sandpiper | *Calidris minutilla* | W | |
| LOSH | Loggerhead shrike | *Lanius ludovicianus* | | |
| LUWA | Lucy's warbler | *Oreothlypis luciae* | R | |
| MALL | Mallard | *Anas platyrhynchos* | W | |
| MAWR | Marsh wren | *Cistothorus palustris* | W | |
| MERL | Merlin | *Falco columbarius* | | |
| MODO | Mourning dove | *Zenaida macroura* | U | |
| NECO | Neotropic cormorant | *Phalacrocorax brasilianus* | W | |
| NOCA | Northern cardinal | *Cardinalis cardinalis* | | |
| NOFL | Northern flicker | *Colaptes auratus* | U | |
| NOHA | Northern harrier | *Circus cyaneus* | | |
| NOMO | Northern mockingbird | *Mimus polyglottos* | U | |
| NOPI | Northern pintail | *Anas acuta* | W | |
| NRWS | Northern rough-winged swallow | *Stelgidopteryx serripennis* | U | |
| NSHO | Northern shoveler | *Anas clypeata* | W | |
| OCWA | Orange-crowned warbler | *Oreothlypis celata* | R | |
| OSPR | Osprey | *Pandion haliaetus* | W | |
| PBGR | Pied-billed grebe | *Podilymbus podiceps* | W | |
| PFLB | Peach-faced lovebird | *Agapornis roseicollis* | U | E |
| PHAI | Phainopepla | *Phainopepla nitens* | D | |
| RCKI | Ruby-crowned kinglet | *Regulus calendula* | R | |
| ROPI | Rock pigeon | *Columba livia* | U | E |
| ROWR | Rock wren | *Salpinctes obsoletus* | D | |
| RTHA | Red-tailed hawk | *Buteo jamaicensis* | | |
| RWBL | Red-winged blackbird | *Agelaius phoeniceus* | W | |
| SAPH | Say's phoebe | *Sayornis saya* | U | |
| SAVS | Savannah sparrow | *Passerculus sandwichensis* | | |
| SNEG | Snowy egret | *Egretta thula* | W | |
| SOSP | Song sparrow | *Melospiza melodia* | R | |
| SPSA | Spotted Sandpiper | *Actitis macularius* | W | |
| SSHA | Sharp-shinned hawk | *Accipiter striatus* | | |
| TUVU | Turkey vulture | *Cathartes aura* | | |
| VEFL | Vermilion flycatcher | *Pyrocephalus rubinus* | R | |
| VERD | Verdin | *Auriparus flaviceps* | D | |
| WAVI | Warbling vireo | *Vireo gilvus* | R | |
| WCSP | White-crowned sparrow | *Zonotrichia leucophrys* | | |
| WEKI | Western kingbird | *Tyrannus verticalis* | | |
| WEME | Western meadowlark | *Sturnella neglecta* | | |
| WEWP | Western wood-pewee | *Contopus sordidulus* | | |
| WFIB | White-faced ibis | *Plegadis chihi* | | |
| WISN | Wilson's snipe | *Gallinago delicata* | W | |
| WIWA | Wilson's warbler | *Cardellina pusilla* | R | |
| WWDO | White-winged dove | *Zenaida asiatica* | D | |
| YEWA | Yellow warbler | *Setophaga petechia* | R | |
| YHBL | Yellow-headed blackbird | *Xanthocephalus xanthocephalus* | W | |
| YRWA | Yellow-rumped warbler | *Setophaga coronata* | R | |

APPENDIX 4. Species list for species of amphibians and reptiles observed along the Salt River in central Arizona (T are species detected along survey transects or S only in study site). Species codes used in ordination figures represent scientific name, except when species were combined (e.g. spiny included desert spiny lizards and any unknown *Sceloporus* species).

| Species codes | Scientific name | Common name | Sighting | Exotic |
|---|---|---|---|---|
| Toad | *Anaxyrus punctatus* | Red-spotted toad | T | |
| Toad | *Anaxyrus woodhousii* | Woodhouse's toad | T | |
| LICA | *Lithobates catesbeiana* | American bullfrog | T | E |
| ASTI | *Aspidoscelis tigris* | Tiger whiptail | T | |
| CADR | *Callisaurus draconoides* | Zebra-tailed lizard | T | |
| COVA | *Coleonyx variegatus* | Western banded gecko | T | |
| DIDO | *Dipsosaurus dorsalis* | Desert iguana | S | |
| Spiny | *Sceloporus magister* | Desert spiny lizard | T | |
| URGR | *Urosaurus graciosus* | Long-tailed brush lizard | T | |
| UROR | *Urosaurus ornatus* | Ornate tree lizard | T | |
| UTST | *Uta stansburiana* | Common side-blotched lizard | T | |
| CRAT | *Crotalus atrox* | Western diamondback rattlesnake | S | |
| LAGE | *Lampropeltis getula* | Common kingsnake | S | |
| TAHO | *Tantilla hobartsmithi* | Smith's black-headed snake | T | |
| TRSC | *Trachemys scripta* | Pond slider | S | E |

## REFERENCES

Allan JD, Flecker AS. 1993. Biodiversity conservation in running waters. *Bioscience* **43**: 32–43.

Aronson MFJ, La Sorte FA, Nilon CH, Katti M, Goddard MA, Lepczyk CA, Warren PS, Williams NSG, Cilliers S, Clarkson B, Dobbs C, Dolan R, Hedblom M, Klotz S, Kooijmans JL, Kühn I, MacGregor-Fors I, McDonnell M, Mörtberg U, Pyšek P, Siebert S, Sushinsky J, Werner P, Winter M. 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society Biological Sciences* **281**: 1471–2954.

Arthington AH, Naiman RJ, McClain ME, Nilsson C. 2010. Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. *Freshwater Biology* **55**: 1–16.

Banville MJ, Bateman HL. 2012. Urban and wildland herpetofauna communities and riparian microhabitats along the Salt River, Arizona. *Urban Ecosystems* **15**: 473–488.

Bateman HL, Merritt DM, Johnson JB. 2012. Riparian forest restoration: conflicting goals, trade-offs, and measures of success. *Sustainability* **4**: 2334–2347.

Beauchamp VB, Shafroth PB. 2011. Floristic composition, beta diversity, and nestedness of reference sites for restoration of xeroriparian areas. *Ecological Applications* **21**: 465–476.

Benayas RJM, Newton AC, Diaz A, Bullock JM. 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. *Science* **325**: 1121–1124.

Bernhardt ES, Palmer MA. 2007. Restoring streams in an urbanizing world. *Freshwater Biology* **52**: 738–751.

Bernhardt ES, Palmer MA. 2011. River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation. *Ecological Applications* **21**: 1926–1931.

Bijoor NS, McCarthy HR, Pataki DE. 2012. Water sources of urban trees in the Los Angeles metropolitan area. *Urban Ecosystems* **15**: 195–214.

Brennan TC, Holycross AT. 2009. *A Field Guide to Amphibians and Reptiles in Arizona*. Arizona Game and Fish Department: Phoenix, Arizona.

Briggs MK, Cornelius S. 1998. Opportunities for ecological improvement along the lower Colorado River and delta. *Wetlands* **18**: 513–529.

Brooks BW, Riley TM, Taylor RD. 2006. Water quality of effluent-dominated ecosystems: ecotoxicological, hydrological, and management considerations. *Hydrobiologia* **556**: 365–379.

Brown DE. 1994. *Biotic Communities: Southwestern United States and Northwestern Mexico*. University of Utah Press: Salt Lake City, Utah.

Colwell RK. 2013. *EstimateS: Statistical Estimation of Species Richness and Shared Species From Samples. Version 9.1. User's Guide and Application*. University of Connecticut: Storrs, Connecticut.

Colwell RK, Coddington JA. 1994. Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions by the Royal Society: Biological Sciences* **345**: 101–118.

Corman T, Wise-Gervais C (eds) 2005. *Arizona Breeding Bird Atlas*. University of New Mexico Press: Albuquerque, New Mexico.

Crother BI (ed). 2008. *Scientific and Standard English Names of Amphibians and Reptiles of North America North of Mexico, with Comments Regarding Confidence in Our Understanding*, 6th edn. Herpetological Circular 37, Society for the Study of Amphibians and Reptiles (SSAR): Salt Lake City, Utah.

Dallimer M, Rouquette JR, Skinner AMJ, Armsworth PR, Maltby LM, Warren PH, Gaston KJ. 2012. Contrasting patterns in species richness of birds, butterflies and plants along riparian corridors in an urban landscape. *Diversity and Distributions* **18**: 742–753.

Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Lévêque C, Naiman RJ, Prieur-Richard AH, Soto D, Stiassny MLJ, Sullivan CA. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews* **81**: 163–182.

Dufour S, Piégay H. 2009. From the myth of a lost paradise to targeted river restoration: forget natural references and focus on human benefits. *River Research and Applications* **25**:568–581.

Dynesius M, Nilsson C. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* **266**: 753–762.

Everard M, Moggridge HL. 2012. Rediscovering the value of urban rivers. *Urban Ecosystems* **15**: 293–314.

Fenner P, Ward WB, Patten DR. 1985. Effects of regulated water flows on regeneration of Fremont cottonwood. *Journal of Range Management* **38**: 135–138.

Fitzhugh TW, Richter BD. 2004. Quenching urban thirst: growing cities and their impacts on freshwater ecosystems. *BioScience* **54**: 741–754.

Gerlak AK, Eden S, Megdal SB, Lacroix KM, Schwarz A. 2009. Restoration and river management in the arid Southwestern USA: exploring project design trends and features. *Water Policy* **11**: 461–480.

Graf WL. 2000. Locational probability for a dammed, urbanizing stream: Salt River, Arizona, USA. *Environmental Management* **25**: 321–335.

Gurnell AM, Shuker L, Lee M, Boitsidis AJ. 2012. Gradients in the biophysical structure of urban rivers and their association with river channel engineering. *River Research and Applications* **28**: 908–925.

Haase EF. 1972. Survey of flood plain vegetation along the lower Gila River in southwestern Arizona. *Journal of the Arizona Academy of Science* **7**: 66–81.

Hall ND, Stuntz BB, Abrams RH. 2008. Climate change and freshwater resources. *Natural Resources and Environment* **22**: 30–35.

Hawley JR, Bledsoe BP. 2011. Channel enlargement in semiarid suburbanizing watersheds: a southern California case study. *Journal of Hydrology* **496**: 17–30.

Hendrickson DA, Minckley WL. 1984. Cienegas: vanishing climax communities of the American Southwest. *Desert Plants* **6**: 1–175.

Kearney TH, Peebles RH, McClintock E, Kearney JTH. 1960. *Arizona Flora*. University of California Press: Berkeley and Los Angeles, California.

Kehr JM, Merritt DM, Stromberg JC. 2014. Linkages between primary seed dispersal, hydrochory, and flood timing in a dryland river. *Journal of Vegetation Science* **25**:287–300.

Kotze DJ, Samways MJ. 1999. Support for the multi-taxa approach in biodiversity assessment, as shown by epigaeic invertebrates in an Afromontane forest archipelago. *Journal of Insect Conservation* **3**: 125–143.

Loaiciga HA. 2009. Long-term climatic change and sustainable ground water resources**.** *Environmental Research Letters* **4**: 035004 (11pp).

Makings E, Butler L, Chew M, Stromberg J. 2011. Noteworthy collections from Tempe Town Lake Riverbed. *Desert Plants* **27**: 3–10.

McClain CD, Holl KD, Wood DM. 2011. Successional models as guides for restoration of riparian forest understory. *Restoration Ecology* **19**: 280–289.

Merritt DM, Cooper DJ. 2000. Riparian vegetation and channel change in response to river regulation: a comparative study of regulated and unregulated streams in the Green River Basin, USA. *Regulated Rivers-research and Management* **16**: 543–564.

Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Henry M, Stevens H, Wagner H. 2013. Vegan: Community Ecology Package. R package version 2.0-8. Available from: http://CRAN.R-project.org/package=vegan (accessed August 2014).

Palmer MA, Lettenmaier DP, Poff NL**,** Postel S, Richter B, Warner R. 2009. Climate change and river ecosystems: protection and adaptation options. *Environmental Management* **44**:1053–1068.

Pyle P, DeSante D. 2012. List of North American birds and alpha codes according to American Ornithologists' Union taxonomy through the 53rd AOU Supplement. Available from: http://www.birdpop.org/alphacodes.htm (accessed June 2013).

Rea AM. 1983. *Once a River: Bird Life and Habitat Changes on the Middle Gila*. University of Arizona Press: Tucson, Arizona.

Rea AM. 1988. Habitat restoration and avian recolonization from wastewater on the Middle Gila River, Arizona. In *Arid Lands: Today and Tomorrow*, Whitehead EE, Hutchinson CF, Timmermann BN, Varady RG (eds). Westview Press: Boulder, Colorado; 1395–1405.

Roberge M. 2002. Human modification of the geomorphically unstable Salt River in metropolitan Phoenix. *The Professional Geographer* **54**: 175–189.

Rood SB, Samuelson GM, Braatne JH, Gourley CR, Hughes FMR, Mahoney JM. 2005. Managing river flows to restore floodplain forests. *Frontiers in Ecology and the Environment* **3**: 193–201.

Rosenberg KV, Terrill SB, Rosenberg GH. 1987. Value of suburban habitat to desert riparian birds. *The Wilson Bulletin* **99**: 642–654.

Scheffers BR, Paszkowski CA. 2013. Amphibian use of urban stormwater wetlands: the role of natural habitat features. *Landscape and Urban Planning* **113**: 139–149.

Seager R, Ting M, Held I, Kushnir Y, Lu J, Vecchi G, Huang HP, Harnik N, Leetmaa A, Lau NC, Li C, Velez J, Naik N. 2007. Model projections of an imminent transition to a more arid climate in Southwestern North America. *Science* **316**: 1181–1184.

Sibley DA. 2000. *National Audubon Society the Sibley Guide to Birds*. Alfred A. Knopf, Inc.: New York, New York.

Stromberg JC, Hazelton AF, White MS, White JM, Fischer RA. 2009. Ephemeral wetlands along a spatially intermittent river: temporal patterns of vegetation development. *Wetlands* **29**: 330–342.

Stromberg JC, Shafroth PB, Hazelton AF. 2012. Legacies of flood reduction on a dryland river. *River Research and Applications* **28**: 143–159.

Sueltenfuss JP, Cooper DJ, Knight RL, Waskom RM. 2013. The creation and maintenance of wetland ecosystems from irrigation canal and reservoir seepage in a semi-arid landscape. *Wetlands* **33**: 799–810.

Trammell EJ, Weisberg PJ, Bassett S. 2011. Avian response to urbanization in the arid riparian context of Reno, USA. *Landscape and Urban Planning* **102**: 93–101.

Uowolo AL, Binkley D, Adair EC. 2005. Plant diversity in riparian forests in northwest Colorado: effects of time and river regulation. *Forest Ecology and Management* **218**: 107–114.

USDA, NRCS. 2010. The PLANTS Database. National Plant Data Center, Baton Rouge, LA 70874-4490, USA. Available from: http://plants.usda.gov (accessed September 2012).

Verberk WCEP, van Noordwijk CGE, Hildrew AG. 2013. Delivering on a promise: integrating species traits to transform descriptive community ecology into a predictive science. *Freshwater Science* **32**:531–547.

Violin CR, Cada P, Sudduth EB, Hassett BA, Penrose DL, Bernhardt ES. 2011. Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems. *Ecological Applications* **21**: 1932–1949.

Walsh CJ, Fletcher TD, Burns MJ. 2012. Urban stormwater runoff: a new class of environmental flow problem. *Plos ONE* **7**: e45814. 10.1371/journal.pone.0045814.

Weisberg PJ, Mortenson SG, Dilts TE. 2013. Gallery forest or herbaceous wetland? The need for multi-target perspectives in riparian restoration planning. *Restoration Ecology* **21**: 12–16.

Wenger SJ, Roy AH, Jackson CR, Bernhardt ES, Carter TL, Filoso S, Gibson CA, Hession WC, Kaushal SS, Martí E, Meyer JL, Palmer MA, Paul MJ, Purcell AH, Ramírez A, Rosemond AD, Schofield KA, Sudduth EB, Walsh CJ. 2009. Twenty-six key research questions in urban stream ecology: an assessment of the state of the science. *Journal of the North American Benthological Society* **28**: 1080–1098.

Western Regional Climate Center (WRCC). 2012. Historical climate information. Desert Research Institute (DRI). Available from: http://www.wrcc.dri.edu/summary/phx.az.html (accessed October 2012).

White J, Stromberg JC. 2009. Resilience, restoration, and riparian ecosystems: case study of a dryland, urban river. *Restoration Ecology* **17**: 1–11.

Ye L, Grimm NB. 2013. Modelling potential impacts of climate change on water and nitrate export from a mid-sized, semiarid watershed in the US Southwest. *Climatic Change* **120**: 419–431.