A Portrait of Changing Community Composition in Urban Wetlands of the Salt River, Phoenix AZ USA

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Abstract

Human activities in Phoenix, Arizona, have left the Salt River dammed, diverted, restored, and ignored. Urban wetlands are vital for many species, offering insight into how ecological communities and management are co-produced within social-ecological systems. Which organisms are most impacted by urban management choices?

We analyzed long-term surveys (2012-2022) of birds, herpetofauna, and plants across three urban wetlands: a recreation area, an unmanaged accidental wetland, and a restored wetland. We assessed species richness, abundance, and diversity. In collaboration with land managers, we removed vegetation from the restored site and harvested biomass from three abundant marsh plants (Arundo donax, Schoenoplectus californicus, and Typha latifolia). Using Hollander beaters, we pulped the biomass to make paper and visualized plant community changes on it, displaying these artworks in community centers to engage local audiences.

Our results show herpetofauna declined in abundance and diversity, while bird populations remained stable. Vegetation abundance increased, and despite invasive species removal efforts, urban plant communities became more cosmopolitan. The unmanaged wetland hosted the highest number of both introduced and rare plant species, along with an increase in culturally significant plants for local Indigenous groups.

This study shows urban wetlands in arid regions support surprising species diversity, and accidental wetlands can complement costly restoration efforts, which are more effective for birds than herpetofauna. Introduced plants do not always threaten native or culturally important species, so the rationale for removal should be considered before implementing management plans. Practical biomass uses, like paper-making, can also foster community engagement with research and stewardship.

Keywords: *Urban ecology, interdisciplinary science, plant ecology, biodiversity, habitat restoration, accidental wetland*

Fig 1 Price Accidental Wetland with an art piece from this study, displaying plant community composition in 2012 (top) and 2022 (bottom). This photo shows *Vitex agnus-castus* (a), an increasingly abundant urban tree and one of the highway overpasses (b) that formed the wetland

Introduction:

Urban development has accelerated across the globe, and well over half the world's population now lives in cities (Acuto et al. 2018, United Nations 2025). Since freshwater is vital for urban development, most cities have been established in or near wetland ecosystems, with watersheds and neighborhoods intimately shaping each other over time, becoming an interwoven urban fabric. While urban wetlands, such as the one shown in Figure 1, are often transformed in this process, they provide myriad ecosystem services (Bolund and Hunhammar 1999), including habitat corridors (Bateman et al. 2015, Stromberg et al. 2016, Andrade et al. 2018, Bateman and Merritt 2020), shelter for humans experiencing houselessness (Palta et al. 2016), flood mitigation (Zedler and Kircher 2005), water quality mitigation and management (Vroom 2018, Childers 2020, Treese et al. 2020), phytoremediation (Feng et al. 2013), carbon sequestration and storage (Mitsch et al. 2013), heat mitigation (Golden 2004) and denitrification (Suchy 2016, Suchy et al. 2020, Handler et al. 2022). These wetlands are often culturally important for many residents, especially Indigenous peoples. In arid landscapes such as the Sonoran Desert, these ecosystem services are even more crucial because they are spatially rare.

Despite this importance, urban wetlands have often been replaced or transformed by the social and ecological inputs and factors that accompany human development (Ehrenfeld 2008, McKinney 2006, Palta et al. 2017). In many cases urban wetlands, like the surrounding city, have become more biologically similar to other urban areas worldwide (McKinney 2006, Padullés Cubino 2019, Cubino et al. 2020). These changes alter the composition of landscape mosaics and biotic communities, potentially jeopardizing species and processes in these ecosystems (Gibbs 2000, Chapin III 2000, Luck et al. 2003, Burkle et al. 2012, Tilman et al. 2014). We constructed a Press-Pulse Diagram (Figure 2; after Collins et al. 2011) to demonstrate some of the pressures, pulses, and services that link the social and biophysical components of urban wetlands (Figure 2).

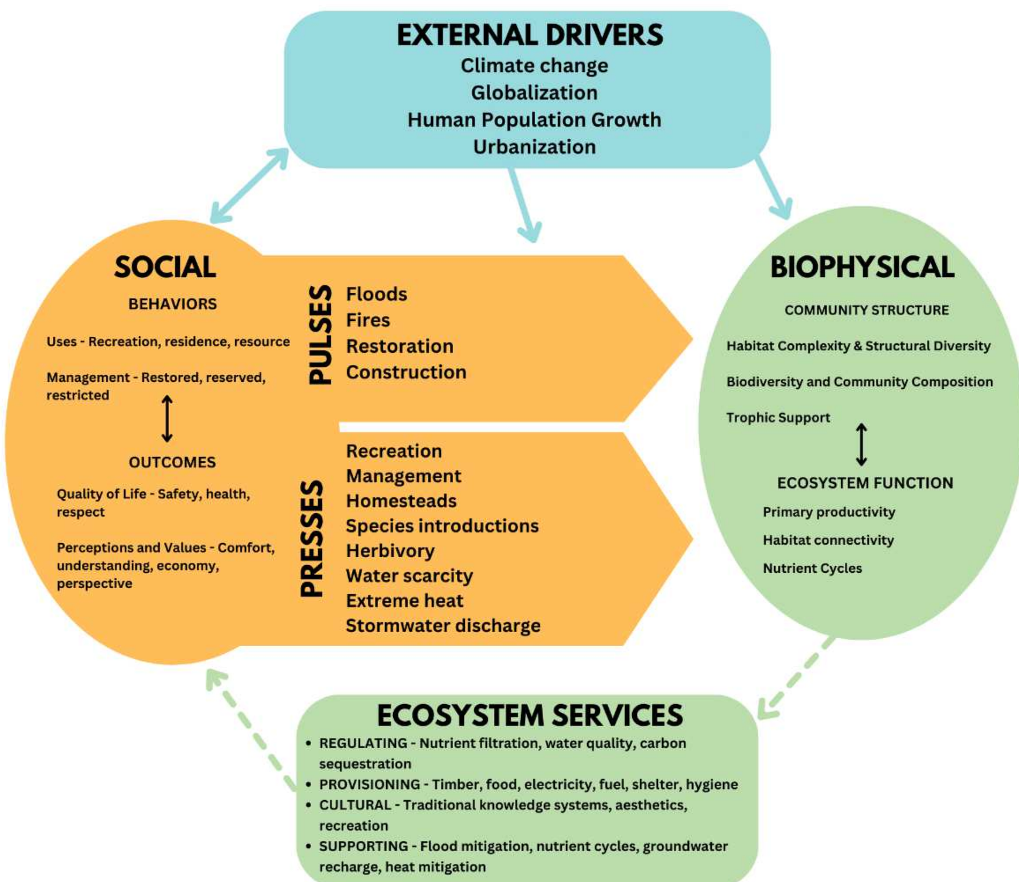

Fig 2 Press-Pulse diagram of urban wetland ecosystems, identifying some of the key dynamics linking social and biophysical aspects of urban wetlands

As cities worldwide grow rapidly in population and area, wetlands are becoming even more vital elements of urban ecological infrastructure (UEI; Childers et al. 2019), contributing to the preservation of urban biodiversity, stability of nutrient cycles, and mitigation of climate risks such as extreme heat and flooding (Childers et al. 2019, Tarabon et al. 2024). To work with urban wetland ecosystems instead of against them, long-term monitoring and citizen engagement must guide management (McPhearson et al. 2016, Kominoski et al. 2018, Bunting et al. 2021, How et al. 2022). In this study we combined long-term monitoring, information on ecosystem management, and artistic exploration to visualize and document changes in urban wetland biotic communities in one of the fastest growing urban areas in the United States–the Phoenix Metropolitan Area.

Methods:

Field Data Collection:

The Salt River Biodiversity Project (SRBP), part of the Central Arizona-Phoenix Long Term Ecological Research Program (CAP), began in 2012. The SRBP surveys the composition of plant, bird, reptile, and amphibian communities at seven study sites along different reaches of the Salt River, following a gradient of urbanization (Bateman et al. 2015, Bateman and Childers 2021, Bateman and Warren 2022, Ramsey-Wiegmann et al. 2024). Appendix I contains a complete list of all plant, bird, reptile, and amphibian species observed since 2012, including scientific binomials, English and Spanish names, and a suite of relevant species characteristics.

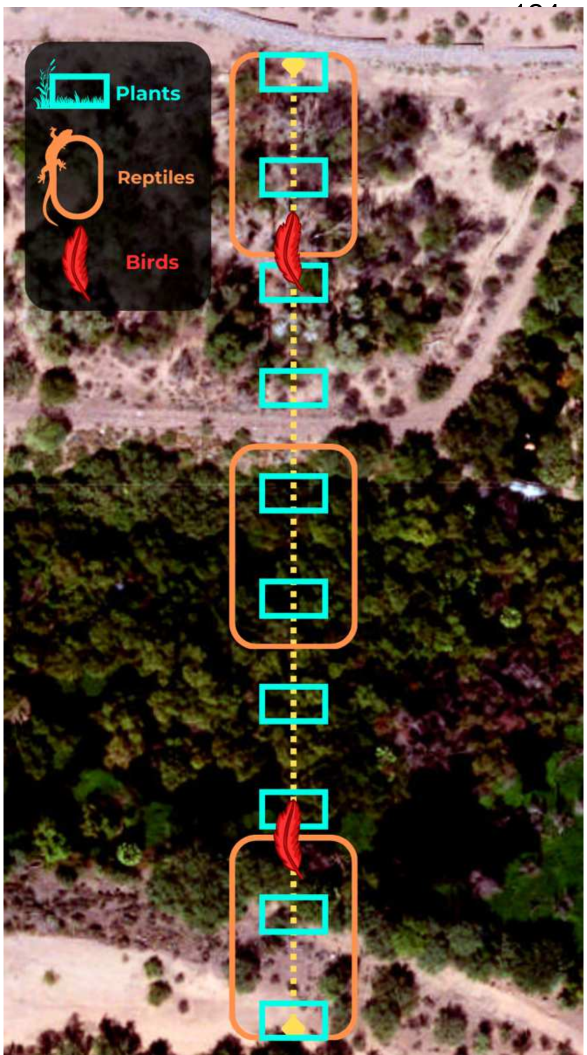

Fig 3 An example transect from Rio Salado, showing bird points (red feathers), herpetofauna survey plots (orange), and vegetation cover assessment plots *(turquoise)*

All three taxa (plants, birds, and herpetofauna) were surveyed along three transects at each site, spaced approximately 150 m apart. Since the width of the river channel varies among sites, the endpoints of transects were determined in 2012 by observing geomorphic and vegetative shifts from wetland to upland habitats. Transects ranged in length from 125-400 m and plots were selected to obtain a sample representative of different habitats across a range from marsh to rocky upland. Figure 3 shows the distribution of plant, bird, and herpetofauna surveys across an example transect at Rio Salado. CAP technicians have conducted bird and herpetofauna surveys continuously since 2012. Vegetation surveys were conducted at the beginning of the project in 2012, and then again ten years later, in 2022.

We surveyed birds seasonally (winter migration, spring pre-monsoon, and late summer post-monsoon) at two point-count stations per transect—six per site (Figure 3). We calculated bird abundance as the greatest number of individuals of a species seen and/or heard at once on each transect to reduce the likelihood of recording the same bird twice. In 2014, we changed methods from a 10-minute point count to a 15-minute point count, so in this analysis we only included the 2014-2022 data (Bateman 2016). We also categorized birds by habitat preference guilds according to Corman and Wise-Gervais (2005) and Cubley et al. (2020).

Reptiles and amphibians, or herpetofauna, were assessed in nine 10 x 20 m^2 plots per site–three distributed along each transect (Figure 3)–using visual encounter surveys, beginning in 2012. Since herpetofauna are more active in warm conditions, surveys were conducted on warm, sunny days with little wind in spring (March-April), summer dry season (May-June), and summer wet season (September-October). The COVID-19 pandemic limited our ability to conduct these surveys, and we only surveyed twice in 2020 and once in 2021 (See Appendix II). To account for this, herpetofauna abundance was analyzed as the greatest number of individuals of each species observed at once on each transect in any given year. These methods are most effective for lizards, and while snakes and anurans are reported, these data likely do not fully represent all reptiles and amphibians present.

In 2012, we assessed the vegetation at each site by recording environmental variables (such as substrate and water level) and plant cover by species. In 2022, we reconducted these surveys at a subset of SRBP sites (see Site Description) using the same methods and plot placement as in 2012 (Bateman et al. 2015), to examine changes in botanical communities after a decade of pressure from urbanization and climate change. We assessed ten 2 m^2 plots (one square meter on each side of the transect) distributed along each transect (30 total plots per site) to capture different zones of the channel, from upland vegetation to marsh and open water (Figure 3).

We visually assessed plots for soil or sediment characteristics (silt, sand, gravel, or cobble), water level, and litter (herbaceous, woody, and human). We then identified plants to species where possible and assessed the abundance of each using Daubenmire cover classes (Daubenmire 1959). We surveyed plants in the winter wet season, the summer dry season, and the summer monsoon season to capture seasonal variation. We collected voucher specimens for identification, with a few exceptions: One of our sites is located on the Salt River Pima-Maricopa Indian Community (SRPMIC) reservation, and they requested that we not collect culturally significant species from their community and provided a list of these species (SRPMIC, 2022). We honored this request at all three of our study sites.

Site Description and History:

Across less than 60 kilometers, as it passes through the Phoenix Area, the Salt River (On'k Akimel, as the Indigenous Akimel O'Odham know it) is dammed, diverted, mined, re-filled, clear-cut, restored, and ignored. While the Hohokam and their descendants have diverted the Salt River's flow to irrigate fields for centuries (Waters & Ravesloot 2001, Howard 2003), this diversion intensified when a group of mostly white farmers and ranchers organized in the early 1900s as the group now known as Salt River Project (Gooch et al. 2007). With federal funding and support, SRP constructed levees and dammed the river east of the city to mitigate flood risk and create a series of reservoirs that supply drinking water and electricity to the residents of the area (SRP 2023). These infrastructure choices isolated the river from its floodplain, deprived riparian forests and mesquite bosques of water, and left a mostly dry riverbed that was primarily used for dumping grounds and gravel pits until the 1990s (DeSemple 2006, Stromberg 2007, Stromberg 2016).

Most of the riverbed is dry, but in a few reaches human activity and infrastructure provide year-round water, a crucial factor in the provision of ecosystem services and ecological functions in arid environments. Some are restoration and recreation areas, where managers have intentionally reintroduced water to bolster specific ecosystem services. Others are accidental wetlands, formed as the unintentional result of human land and water use choices, such as runoff from irrigation and highways (Palta et al. 2017). We selected three perennially inundated wetlands—one reach heavily regulated by dams upstream of the city (Tonto), one urban accidental wetland (Price), and one urban restoration area (Rio)—which present hydro-ecological analogues to riparian zones within the riverbed itself. All three sites are subject to pressures and pulses associated with urbanization, but each is managed differently.

The Tonto site is located within Tonto National Forest, upstream of the urban sprawl of metropolitan Phoenix (Figure 4). While not directly bordered by urban development, this site is still shaped by human activity. Stewart Mountain Dam regulates river flow in this area in response to downstream demands for water supply and electricity generation. Many citizens also use the area for recreation, including

Fig 4 Map of Case Study Sites. Tonto (right) is a managed remnant wetland upstream of the city. Price (center) is an accidental wetland formed by human infrastructure. Rio (left) is a restoration project in the heart of downtown Phoenix. (Google Earth, 2024)

construction of the interchange in the early 2000's and is mostly sustained by runoff from the highways' storm drains, from agricultural fields on the SRPMIC reservation to the north, and occasionally from reclaimed wastewater discharge from the City of Mesa's Northwest Water Reclamation Plant (City of Mesa 2023). This site sits on the border of the cities of Mesa and Tempe and the SRPMIC and is also overseen by the Arizona Department of Transportation. Since the jurisdiction of this area complicated, management is limited to simply prohibiting access. Yet over the years, extensive informal human settlements have repeatedly formed in this area (and have repeatedly been dispersed by the SRPMIC and the City of Tempe). The presence of so many urban pressures and lack of formal management make this site a case study of the remarkable short-term transformation of an urban dry riverbed to a thriving urban wetland with little intervention and oversight.

The third site, Rio Salado, is a former dumping ground in the heart of downtown Phoenix (Figure 4). The City of Phoenix, Audubon Southwest, and US Army Corps of Engineers restored the site in the late 1990's and early 2000's following a city-wide ballot measure (DeSemple 2006). Restoration efforts such as Rio Salado have been identified as key for sustaining ecosystem services by environmental scientists worldwide, as shown by the United Nations' declaring the 2020's the UN Decade on

Ecosystem Restoration (UN 2020). At Rio Salado, the $110+ million ongoing restoration and management efforts include removing litter and unwanted plant species, creating and maintaining groundwater wells to keep restored wetlands hydrated, planting and irrigating native plant species, and displacing informal settlements. The ecosystem provides crucial habitat patches for urban-dwelling wildlife, aesthetic and recreational opportunities for Phoenicians to engage with the Salt River, culturally important plants for local Indigenous groups to harvest, and vital shade and heat mitigation for individuals without shelter.

Data Analysis

Because birds, herpetofauna, and plants were surveyed in different seasons, we used annual means and totals to analyze all three groups. First, we examined each site over time to monitor how the unique factors in each area shape the communities within. Then, we combined all three sites to understand metapopulation dynamics at a river-wide scale. Because so many factors varied among the sites, we did not statistically analyze for differences among sites. At both the site and river-wide level, we examined overall abundance and richness for all groups (birds, herpetofauna, and plants), then assessed groups by shared characteristics (such as habitat preference and growth habit, detailed below) to further reveal shifts in community composition.

Reptiles and amphibians (herpetofauna) were the most sparsely recorded group in the study, and we analyzed annual totals for richness and abundance as well as each species' abundance and the abundance of native species. We analyzed bird observations for combined total abundance and species richness at the site level. For further analysis, we categorized and analyzed the bird data by habitat preferences (obligate or facultative riparian, marsh, upland, woodland, urban, or generalist) according to Corman and Wise-Gervais (2005) and Cubley et al. (2020).

Since plants play a crucial role as the base of trophic energetics and as essential components of ecosystem structure and function (Bateman and Merritt 2020, Mitchell et al. 2023), we analyzed the vegetation data in the most detail. We analyzed plant species richness using species accumulation curves and abundance using annual means of the percent cover of each species at each site (Daubenmire 1959). We used the Shannon Diversity Index (Shannon 1948, Clarke and Warwick 2001, Magurran 2004) to assess richness and abundance together. Finally, we examined community composition at the species and genus level by categorizing plants by growth habit, USDA wetland indicator status (USDA 2023), biogeographical range, vegetation management policy of the respective site (such as whether managers consider a species invasive or prohibited, the list of which differed among management groups), and cultural importance to the Akimel O'Odham and Piipaash Peoples *(SRPMIC, 2022).* Out of respect for tribal data sovereignty, we do not delve into the traditional uses and stories from which these plants derive their cultural significance, but we did include the category of culturally important plants in our analysis. This allowed us to assess how plants that have lived in relationships with the Akimel O'Odham people for centuries are becoming more or less abundant in the face of contemporary urbanization.

Integrating Ecological Data, Stewardship, Cultural Relevance, and Art

To effectively understand complex social-ecological systems, embrace diverse ways of knowing, and respond to rapid urbanization and climate change, many scholars have called for ecological research to be integrated with ecosystem stewardship, public outreach, and the arts and humanities (Nabhan 2004, Kimmerer 2013, Nelson & Vucetich 2018, National Academy of Sciences and Engineering 2018, Heras et al. 2021, Artmann 2023). Visual art presents opportunities to communicate data in new forms and new venues, expanding the reach of ecological research beyond academia (Chin 1991, Heras et al. 2021). Printmaking is modular and repeatable, so it is well suited to integrate quantitative data with art. To move beyond visualizing SRBP data through art to integrating these pieces with ongoing ecological restoration efforts, we worked with City of Phoenix land managers at Rio Salado to harvest the three most common graminoid marsh plants in this study: *Arundo donax* (Giant Reed), *Schoenoplectus californicus* (California Bullrush), and *Typha latifolia* (Broadleaf Cattail). The City of Phoenix, like many land managers (Bansal et al. 2019) considers *T. latifolia* and *A. donax* to be invasive, and all three species regularly clog storm drains that are crucial water inputs for the restoration area. Normally City of Phoenix sends these removed plants to landfills, where they emit methane during decomposition.

To explore a less wasteful way to use these removed plants, we experimented with making paper by hand from the biomass of each species, investigating a potential provisioning service of common urban wetland plants. We used a method called field retting, which entails aging the plant biomass in the sun, allowing microorganisms to consume much of the excess tissue, then soaking and steaming the fibers to separate out layers of plant material. We stripped the most lignin-rich layers from the plants by hand since they reduce the tensile strength of paper fibers but are very energy-intensive to remove mechanically (Verheris et al. 2004). We boiled the remaining cellulose-rich fibers in a caustic solution (pH ≈ 11).

Different species required different cooking times, ranging from 90 minutes to 12 hours, in order to obtain the appropriate pliability. After rinsing the fibers, we macerated them in a Reina Hollander beater (Reina 2024) to break down and soften the fibers, creating pulp. We suspended the pulp in vats and pulled it into sheets using molds and deckles. We used a hydraulic press and ventilated dryer box to remove any moisture from the sheets. By engaging with these plants and the ecosystem they inhabit in a physical way, we activated a more embodied way of learning about and from them.

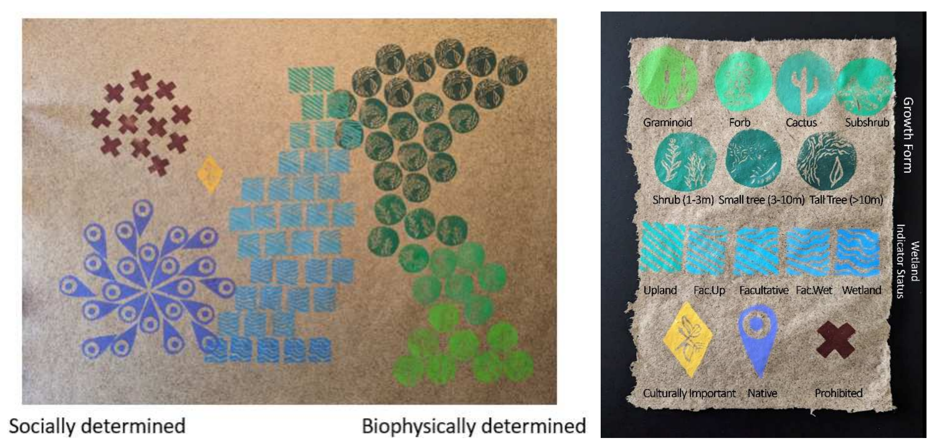

Fig 5 An example art piece made in this study. Each icon is a hand carved linoleum relief print representing 1% annual cover of a group of plants, and groups are arranged on the page from human attitudes about plants (left) to their biology and ecology (right)

Since these plants are a vital foundation of urban wetland communities, we used these papers as a foundation for hand printed community composition graphics. Each of the case study sites was represented by two sheets of paper, one made from the most abundant marsh graminoid in 2012 (when SRBP began) and one made from the most abundant species a decade later, in 2022. We carved linoleum blocks to print plant community composition data on these sheets. Each printed block is a “pixel” representing 1% total annual cover of a group of plants at the site (Figure 5). We printed socially determined categories (prohibited, biogeographically native, and culturally significant) on the left side of the page, and the growth habit, determined by the organism itself, on the right. Wetland indicator status is in the middle, because it describes the likelihood of a species’ presence in wet or dry environments, but is ultimately decided by the USDA, a semi-political body subject to social pressures. Visualizing data this way unlocks alternative approaches to analysis and allows data to enter new spaces, such as art galleries and community science centers, including the Nina Mason Pulliam Rio Salado Audubon Center, where the pieces have been incorporated into exhibits about the ecosystem’s history and future.

Results

Long-term SRBP data illustrated several overarching trends for urban wetland wildlife communities, as well as trends that differed from site to site. Reptiles became less abundant and less diverse across all sites over time, while urban bird populations along the river have remained stable, and even increased in abundance in the restoration area. Plant communities were more abundant and species rich in 2022 than in 2012, with the urban sites supporting more abundant yet more homogenous communities than the site on the urban periphery. We first reviewed site level changes, which differed depending on management approaches. We then combined the sites to understand larger trends across the urban river channel.

Site-specific trends

Tonto (managed remnant wetland):

Tonto supported the greatest number of reptile species and was home to several lizard and snake species not found in urban sites, including *Callisaurus draconoides* (Zebra-tailed Lizard), *Leptotyphlops humilis* (Western Threadsnake), *Salvadora hexalepis* (Western Patch-nosed Snake), and *Sceloropus magister* (Desert Spiny Lizard). Tonto also supported the most birds, in both 2012 and 2022. Urban birds were less prevalent at this site, and facultative riparian birds made up most of the community. *Phainopepla nitens,* Desert Cardinal, were commonly recorded at Tonto, but were absent from urban sites. *Phainopepla* eat and disperse *Phoradendron californicum* (Mesquite Mistletoe; Aukema & Martinez 2002), which was also more commonly observed at Tonto than urban sites. Since *P. californicum*

Fig 6 Community Composition of Tonto 2012 (on Typha latifolia paper) and 2022 (on Arundo donax paper)

Key to plant groups, each icon representing 1% annual cover or a group of plants

parasitizes the most common tree in these ecosystems, it could contribute to lower overall plant abundance. The Tonto plant community did not experience the growth in vegetative cover observed in urban sites but became more species rich (See River-wide trends section below and Figure 9). Our data show lower abundance in 2022 than 2012 (Figure 6) among obligate wetland plants (loss of approximately half of this group) and tall trees (loss of approximately two thirds of this group), suggesting their higher vulnerability to ongoing drought and grazing. Marshes and riparian gallery forests are vital for many bird species, including the endangered Southwestern Willow Flycatcher, *Empidonax traillii extimus,* which was historically found along the Salt and Verde Rivers, which include multiple of its federally designated Critical Habitat areas (Sogge et al. 2003, USFWS 2023). The loss of these vegetation patches could have long-term implications for bird populations even though our findings show stable bird abundance across the first decade of monitoring. Grazing could also influence the increased species richness and Shannon Diversity Index of Tonto, as many species recorded in 2022 but not 2012 were grasses and annual forbs that are well-adapted to grazing. US Forest Service management efforts to stop the spread of “noxious weeds” appear to have been somewhat successful, since these species cover a similar extent of the site as they did in 2012 (Figure 6). However, Culturally Important Species declined at Tonto (Figure 6), the only site where we observed this trend, indicating a potential disconnect between Federal conservation priorities and those of Indigenous land stewards.

Price (unmanaged accidental wetland):

Price is a pocket of relatively wild habitat surrounded by an urbanized landscape. Since we are some of the only groups of people who are in this site, few paths larger than beaver and javelina size cut through the dense stands of *Arundo donax* and *Tamarix spp.* These thick walls of near-impassible vegetation make this site the most difficult to sample. These monotypic stands were a major component of the plant abundance at this site, which grew 59.5% since 2012. Despite the increasing abundance of these prolific cosmopolitan species (and therefore slight reduction in Shannon Diversity Index, from 2.315 to 2.19), species richness did not decline. Native species and those considered culturally important to the Akimel O'Odham have also become more abundant (Figure 7).

We found the two rarest plant species in our surveys at this site, both obligate wetland plants that have found a suitable niche in a

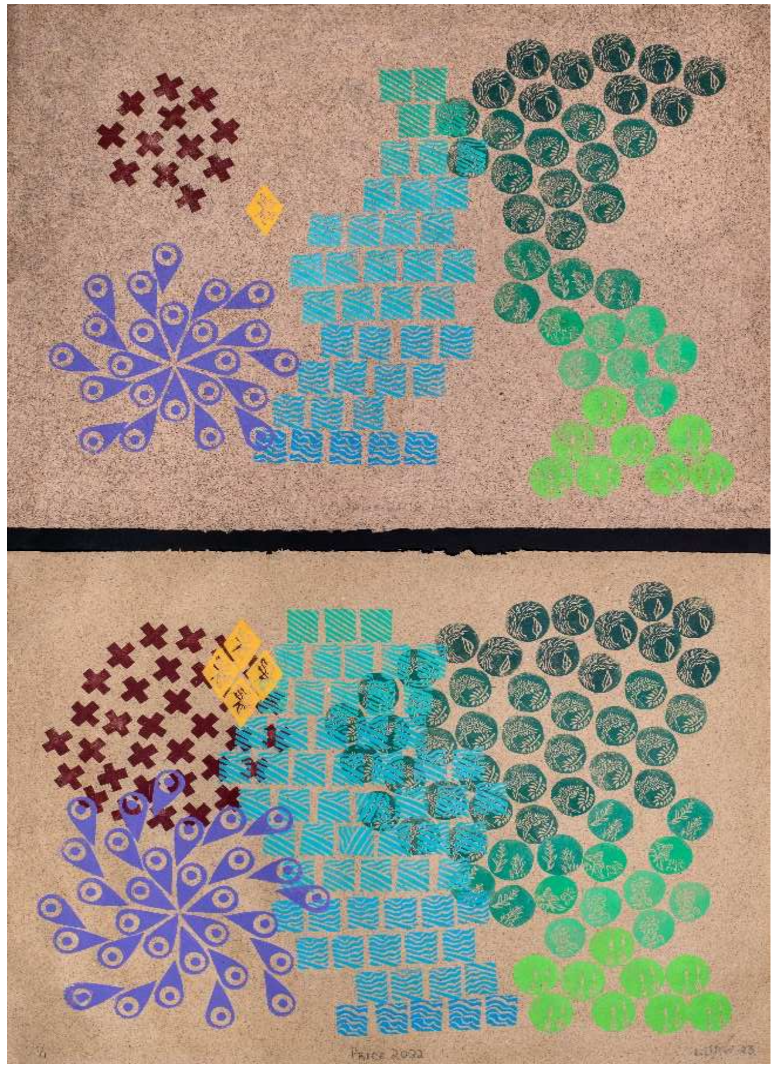

Fig 7 Plant Community Composition at Price (Accidental Wetland) in 2012 (on Typha latifolia paper) and 2022 (on Arundo donax paper)

Key to plant groups, each icon representing 1% annual cover or a group of plants

waterlogged storm drain discharge channel. *Ammannia coccinea,* a wetland plant that is more common at higher elevations in the region, and *Ludwigia erecta,* a typically tropical species that has been found at this site for over a decade but nowhere else within 1000 km. We found the fewest reptiles at this site, both in terms of abundance and species richness. Even common species such as *Uta stansburiana,* the Common Side-blotched Lizard, have become less abundant since 2012. Bird abundance and richness did not change at Price over the course of the study, but the heterogeneous habitat at the site supports birds of all habitat preference guilds. Migratory waterfowl use this site during the winter months and the reach was home to fewer urban habitat-preference birds than the other urban site, Rio Salado.

Rio Salado (restored urban wetland):

Rio Salado provides vital habitat and resources for wildlife in the midst of central Phoenix. Plants grew 49.7% in abundance from 2012 to 2022 (45.2% to 67.6% cover) at Rio Salado (Figure 8), but the Shannon Diversity Index was lower (2.263 in 2022 as compared to 2.617 in 2012), likely indicating that increase in plant abundance was due to repeated plantings of some species and prolific spread of others. Some of these dominant species, such as Willows, Cottonwoods, and Brittlebush (*Salix gooddingii, Populus fremontii, Encelia farinosa,* respectively) were intentionally planted and nurtured by restoration agents such as city park rangers, volunteers, and nonprofits. Others, such as Chaste Tree, Giant Reed, Globe Chamomile, and Floating Water Primrose (*Vitex agnus-castus, Arundo donax, Oncosiphon piluferum,* and *Ludwigia peploides,* respectively), recolonized from the

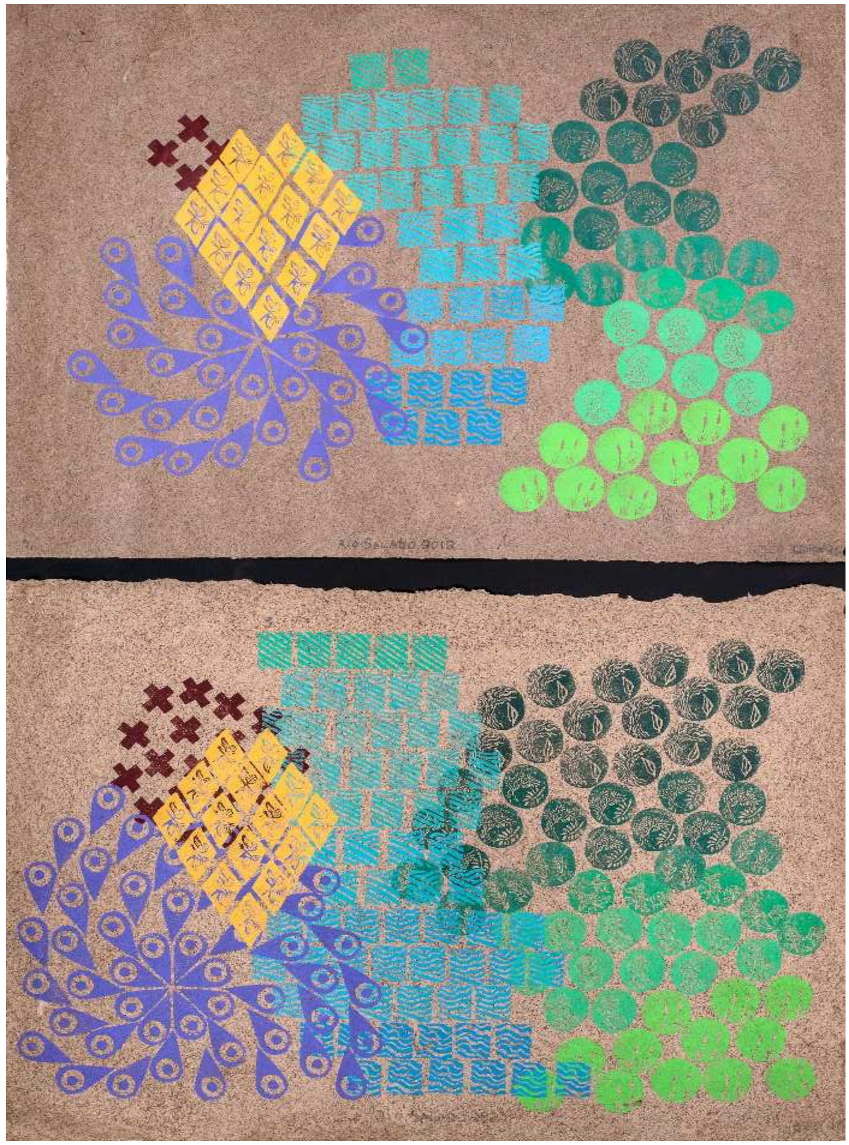

Fig 8 Community Composition at Rio Salado Habitat Restoration Area in 2012 (on Schoenoplectus californicus paper) and 2022 (on Typha latifolia paper)

Below: Key to plant groups, each icon representing 1% annual cover or a group of plants

surrounding urban matrix and reestablished despite the earnest and costly efforts of land managers to eradicate them. Despite declining evenness among plant species (Table 1), plants of all growth habits increased in abundance (Figure 8), creating complex habitat for wildlife. Bird populations have taken advantage of this intricate habitat at Rio Salado, which was the only site where annual mean bird abundance increased during the study—an increase of 56.7% from an average of 68.5 individual observations in 2014 to 107.3 in 2022 (Figure 9), with increases across all habitat preference types. Herpetofauna populations declined, consistent with the overall metacommunity trend, but reptiles and amphibians were roughly twice as abundant and species rich at Rio Salado compared with Price, the other urban site.

Table 1 Annual Plant Species Richness and Evenness (Shannon Diversity Index) for each site in 2012 and 2022. All sites showed an increase in species richness, but the non-urban site (Tonto) became more even while the urban sites became more homogenous

	Tonto 2012	Tonto 2022	Price 2012	Price 2022	Rio 2012	Rio 2022
Mean Annual Plant Species Richness	25.333	39.333	27.5	29	30	37
Shannon Diversity Index	2.193	2.44	2.315	2.19	2.617	2.263

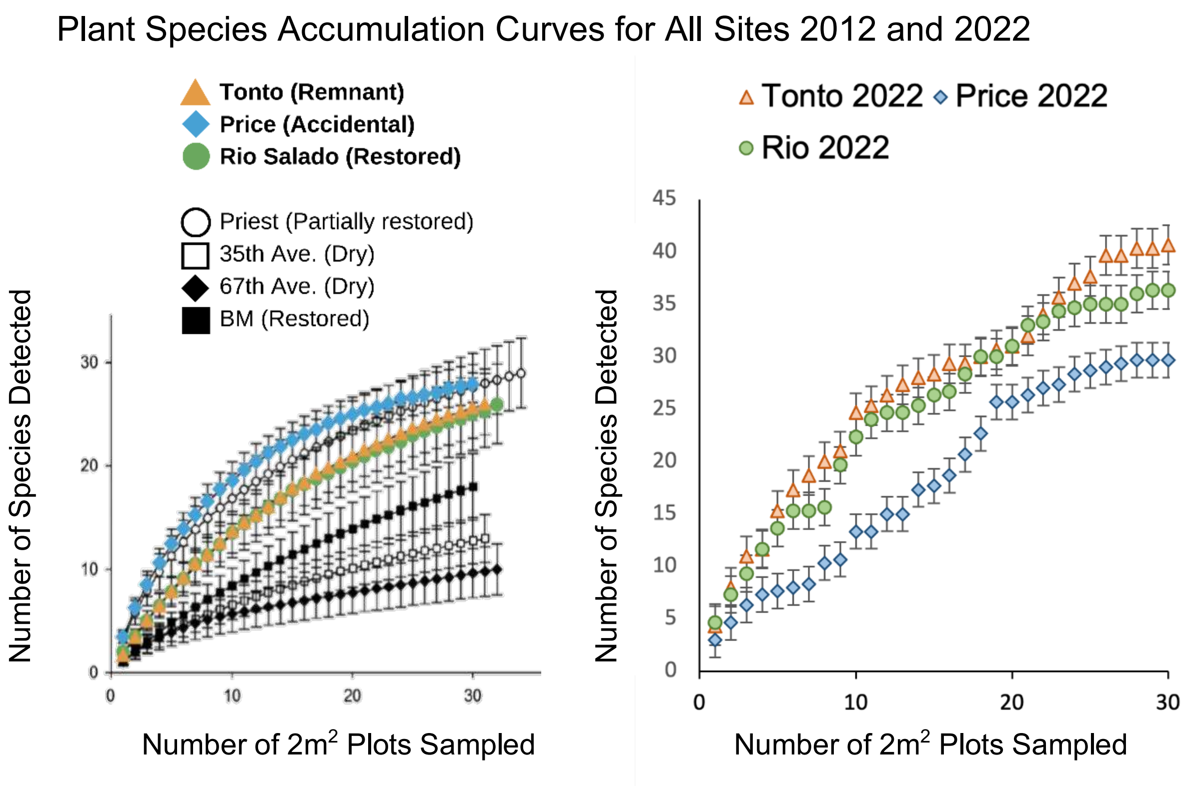

Fig 9 Plant Species Accumulation Curves for all sites. Note the black and white data points on the 2012 (left) chart are SRBP sites that have not been resurveyed (Bateman et al. 2015)

River-wide trends:

When analyzed together as a metacommunity, there were several overarching trends for wildlife along the urban Salt River. Plants at the urban sites were more abundant and species-rich in 2022 than 2012, but the non-urban site showed the greatest increase in species richness (Table 1; Figure 9). The urban accidental wetland was one of the most species rich in 2012 but was the least species-rich in 2022. Plant species richness did not decrease at any of the sites, but both urban sites became less more diverse.

A temporal linear regression of bird communities at the three sites combined showed an increase in species richness over the study ($p=0.006$;, $r^2=0.695$ Figure 10), and habitat restoration efforts at Rio Salado appear to have supported growing bird abundance. On the other hand, reptiles and amphibians became less numerous and diverse ($p=0.0003$, $r^2=0.816$) at the urban sites since 2012 (Figure 11). Tonto, outside the city, showed a stable trend. While difficulties in observing reptiles in densely vegetated areas could lead to this finding, the dangers of urbanization for herpetofauna– including cars, cats, increased heat, and soil characteristics–are well documented (Andrews et al. 2008, Todd et al.2010, French et al.2018, How et al. 2022).

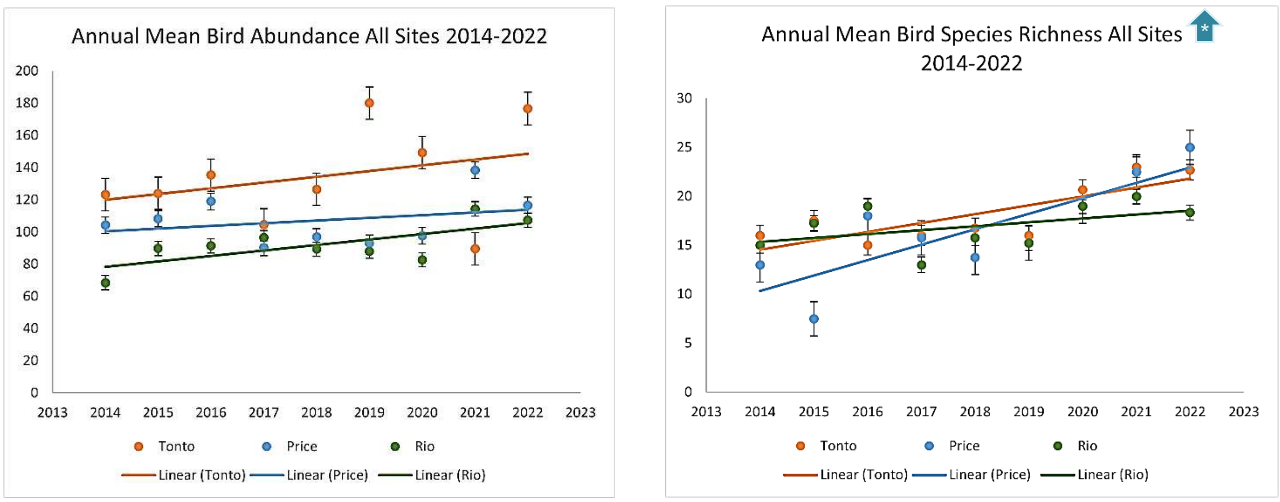

Fig 10 Bird Abundance and Species Richness for all sites (Annual Means) from 2014 to 2022. Error bars are standard error and arrows with asterisks indicate p<0.05 for all sites combined

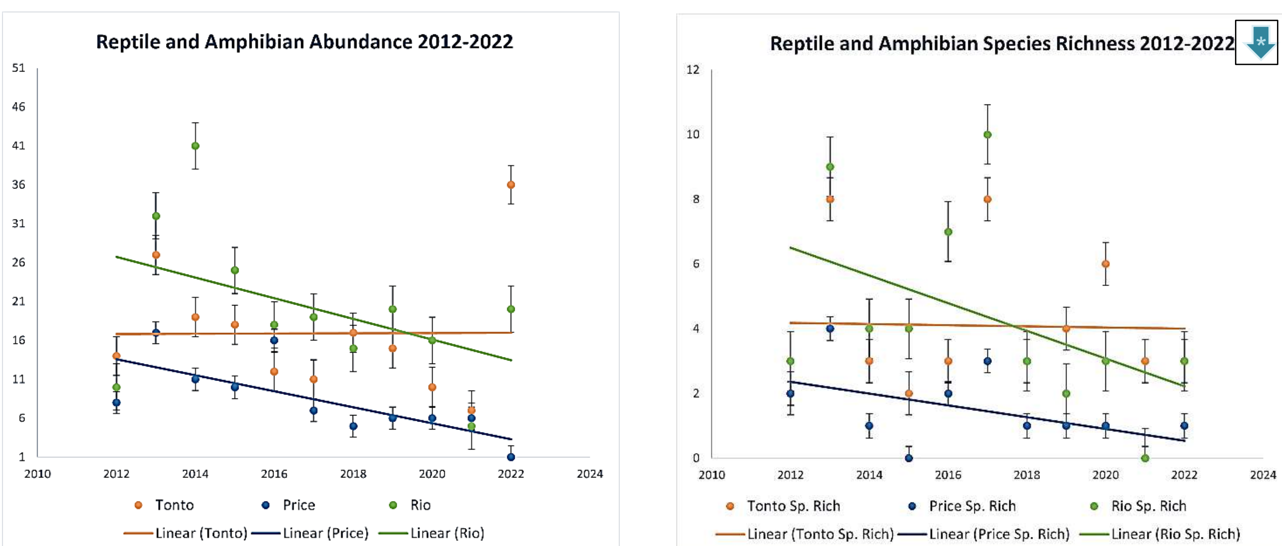

Fig 11 Herpetofauna Abundance and Species Richness for all sites (Annual Means) from 2014 to 2022. Error bars are standard error and arrows with asterisks indicate p<0.05 for all sites combined

Discussion

Urbanization, climate change, and human land use decisions are exerting increasing pressures on aridland wetlands, altering the ecosystem and the services they provide (Jones et al. 2010). In the urban Salt River, perennial water availability from storm drains, agricultural fields, and restoration efforts supported increased plant abundance over the last decade, which in turn created complex habitat for increased bird abundance at some sites. The higher abundance among obligate and facultative wetland plant species at the urban sites suggests that urban runoff and restoration stewardship offset the effects of ongoing regional drought, and the effects of grazing seen in our non-urban plant communities at the Tonto site (Murphy & Ellis 2017, Williams et al. 2022).

However, reptile and amphibian populations declined, suggesting the vulnerability of herpetofauna to urbanization, habitat homogenization, and climate change (Sinervo et al. 2010, Bateman and Merritt 2020, Delaney et al. 2021, Souza et al. 2023). In social-ecological systems such as urban wetlands, human stewardship is necessary for ecological stability, and long-term monitoring is critical for understanding the results of management choices (Ramalho & Hobbs 2012, Nelson & Vucetich 2018, Prior et al. 2018). We found different outcomes of the disparate management approaches at all three study sites.

The remnant wetland at Tonto is primarily managed for recreational purposes. The plant community has shifted towards more upland and shorter stature plants, with increases in grasses, forbs, and thorny shrubs, many of which are well adapted to grazing. Native plant species were more abundant in 2022 than 2012, but culturally significant plants for local Indigenous groups were less abundant in the more recent surveys suggesting a disconnect between conservation efforts based on biogeography (such as US Forest Service management policies) and those focused on plants with cultural ties. Habitat structure became more homogenous as trees recruited fewer new saplings and marsh patches became less common, likely due to combined pressures of horse grazing, controlled hydrology, and ongoing drought (Catford et al. 2011, Ballut-

Dajun et al. 2022, Hunold & Britton 2022, Williams et al. 2022). However, this non-urban reach of the Salt River is home to stable bird and reptile populations, including species we did not observe in urban study sites suggesting some species benefit from less densely vegetated habitat structure.

Wetland plant communities at the Price site increased in percent cover between 2012 and 2022, but did not become more species rich. *Arundo donax* and *Tamarix sp.* were largely responsible for this increase, but native, culturally important, and regionally rare plant species also increased in abundance. This increased plant abundance coincided with stable bird richness and abundance suggesting that even with minimal or no management, urban wetland ecosystems can be important habitat for urban birds and for rare or culturally important plants. However, reptiles and amphibians became less abundant, consistent with research showing how urban pressures such as cats, roads, increased flooding, and the urban heat island effect may threaten the survival of herpetofauna in urban ecosystems (Matheson 1944, Gardner 2001, Vredenberg & Wake 2007, Andrews et al. 2008, Hamer & Mcdonnell 2010, Todd et al. 2010, Duarte et al. 2012, French et al. 2018, How et al. 2022).

Management, Restoration, and Conservation Implications

Restoration and management efforts at the study sites fostered an increase in native plant abundance but did not prevent the introduction and growth of cosmopolitan and prohibited plant species. This is likely because efforts at managing plant populations are designed to react to the spread of undesirable species rather than address underlying environmental causes of their colonization and success, such as flow regimes, grazing, or soil characteristics (Zavaleta et al. 2001, Stromberg et al. 2007, Stromberg et al. 2009, Suding 2011, Bunting et al. 2021). The unmanaged site also supported rare and culturally important plants alongside abundant introduced species. This mosaic of native and introduced plant species supports a similarly cosmopolitan animal community. Reptiles and amphibians were more abundant at Rio Salado than at the other urban site, but still showed population declines, suggesting that herpetofauna communities are vulnerable even in active restoration areas. However, these restoration efforts supported increasingly abundant bird populations. The growing bird community and larger reptile numbers at Rio Salado illustrate the importance of strong social-ecological relationships; Audubon Southwest and Liberty Wildlife, two primarily bird-focused conservation organizations, are key partners in the habitat rehabilitation efforts at Rio Salado. Their stewardship has aided the growing wildlife populations despite the many threats urbanization poses to birds and reptiles. In turn, vibrant wildlife communities help these organizations connect people with their environment and advocate for ecosystem stewardship.

By visualizing the data on plant community composition change through relief prints on paper made by hand from plant species at each site, we presented the data from this long-term monitoring program in a novel and embodied way. We found that *Arundo donax, Schoenoplectus californicus,* and *Typha latifolia*, all commonly targeted for removal in urban wetlands, can be used to make paper, revealing a potential pathway to align ecosystem management, less wasteful material provisioning, and locally-engaged arts communities. The resulting artworks also expanded the audience for our findings, connecting long-term ecological research with the public and with practitioners of ecosystem stewardship.

The United Nations Decade on Ecosystem Restoration (UN 2020) and International Ramsar Convention on Wetlands (Bridgewater and Kim 2021) both stress the critical need to conserve and restore wetland ecosystems for the stability of the biosphere. Urban ecosystems present complex challenges for wetland restoration, but also opportunities for novel modes of stewardship. We recommend that to work towards these ambitious conservation goals, urban wetland management efforts should consider the tradeoffs associated with invasive species removal before initiating eradication projects that are often costly, ineffective, and left unmonitored. Instead, managers should focus holistically on goals such as increasing habitat complexity, supporting culturally significant plant populations, and protecting accidental wetlands to support low-cost UEI. Conservation groups and urban ecologists should also explore new approaches to effectively address declining urban reptile and amphibian populations within wetland habitats. Finally, ecosystem managers and researchers should embrace alternative modes of outreach–integrating science, management, and art to diversify our ways of knowing and stewarding urban wetlands.

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Appendix I: Species Lists

Ia: PLANT SPECIES

Scientific Binomial	**Common Name (English)**	**Nombre Común (Español)**	***Family***	***Growth Habit***	***Wetland Indicator Status***	***Native (N) or Introduced (I)***
Abronia angustifolia	*Narrow leaf sand Verbena*	Arena Púrpura Verbena	Nyctaginaceae	Forb	Facultative Upland	N
Acacia farnesiana	*Sweet Acacia*	Acacia dulce	Fabaceae	Small Tree	Facultative Upland	N
Acacia greggii	*Catclaw Acacia*	uña de gato	Fabaceae	Shrub	Obligate Upland	N
Acacia stenophylla	*Shoestring Acacia*	Acacia de Agujetas	Fabaceae	Tall Tree	Obligate Upland	I
Ambrosia ambrosioides	*Canyon bursage*	chicura	Asteraceae	Shrub	Facultative	N
Ambrosia deltoidea	*Triangle-leaf bursage*	chicurilla	Asteraceae	Subshrub	Facultative Upland	N
Ambrosia eriocentra	*Woolly bursage*	chicurilla	Asteraceae	Shrub	Facultative Upland	N
Ambrosia monogyra	*Singlewhorl burrobush*	jecota	Asteraceae	Shrub	Obligate Upland	N
Ambrosia salsola	*Cheesebush*	jecota	Asteraceae	Subshrub	Obligate Upland	N
Ammannia coccinea	*Scarlet toothcup*	palo de agua	Lythraceae	Forb	Obligate Wetland	N
Amsinckia tessellata	*Fiddleneck*	cedkam	Boraginaceae	Forb	Facultative Upland	N
Amsinckia menziesii var. intermedia	*Fiddleneck*	cedkam	Boraginaceae	Forb	Facultative Upland	N
Aristida purpurea	*Purple Three Awn*	tres barbaras purpuras	Poaceae	Graminoid	Facultative Upland	N
Arundo donax	*Giant Reed*	caña común	Poaceae	Graminoid	Facultative Wetland	I
Atriplex canescens	*Fourwing Saltbush*	cenizo	Amaranthaceae	Shrub	Facultative	N
Atriplex lentiformis	*Big Saltbush/quail bush*	cenizo	Amaranthaceae	Shrub	Facultative	N
Atriplex polycarpa	*Cattle Saltbush*	cenizo	Amaranthaceae	Shrub	Facultative Upland	N
Baccharis salicifolia	*Seepwillow*	batamote	Asteraceae	Shrub	Facultative	N
Baccharis sarothroides	*Desert Broom*	romerillo	Asteraceae	Shrub	Facultative Upland	N
Bebbia juncea	*Chuckwalla's Delight*	Palo dulce	Asteraceae	Subshrub	Facultative	N
Boerhavia coccinea	*Scarlet spiderling*	Abrojo rojo	Nyctaginaceae	Forb	Obligate Upland	N
Boerhavia erecta	*Erect Spiderling*	Golondrina	Nyctaginaceae	Forb	Facultative Upland	N

Boerhavia gracillima	*Slimstalk spiderling*	Tomatillo	Nyctaginaceae	Forb	Obligate Upland	N
Boerhavia wrightii	*Largebract spiderling*		Nyctaginaceae	Forb	Facultative Upland	N
Boerhavia intermedia	*Five-wing spiderling*		Nyctaginaceae	Forb	Obligate Upland	N
Bouteloua aristidoides	*Needle Grama*		Poaceae	Graminoid	Facultative Upland	N
Bouteloua barbata	*Six Weeks Grama*	Navajita	Poaceae	Graminoid	Facultative Upland	N
Bowlesia incana	*Hoary Bowlesia*	Perejillito	Poaceae	Forb	Facultative Upland	N
Brassica tournefortii	*Sahara Mustard*	Mostaza Africana	Brassicaceae	Forb	Facultative Upland	I
Bromus rubens	*Red Brome*	Bromos	Poaceae	Graminoid	Facultative Upland	I
Calibrachoa parviflora	*Seaside petunia*	Petunia Silvestre	Solanaceae	Forb	Facultative Wetland	I
Camissonia californica	*California suncup*	Copas de sol	Onagraceae	Forb	Facultative	N
Castilleja exserta	*Purple Owl's Clover*	Pincel de Indio Morado	Orobanchaceae	Forb	Facultative	N
Cenchrus ciliaris	*Buffelgrass*	Pasto Buffel	Poaceae	Graminoid	Obligate Upland	I
Chaenactis stevioides	*Desert pincushion*		Asteraceae	Forb	Obligate Upland	N
Chilopsis linearis	*Desert Willow*	Mimbre	Bignoniaceae	Small Tree	Facultative	N
Cryptantha angustifolia	*Narrow leaved Cryptantha*		Boraginaceae	Forb	Facultative Upland	N
Cryptantha barbigera	*Bearded Cryptantha*		Boraginaceae	Forb	Facultative Upland	N
Cryptantha decipiens	*Gravelbar Cryptantha*		Boraginaceae	Forb	Facultative Upland	N
Cryptantha muricata	*Pointed Cryptantha*		Boraginaceae	Forb	Facultative Upland	N
Cylindropuntia acanthocarpa	*Buckhorn Cholla*	Choya Espinosa	Cactaceae	Cactus	Obligate Upland	N
Cylindropuntia bigelovii	*Teddy Bear Cholla*	Choya Guera	Cactaceae	Cactus	Obligate Upland	N
Cylindropuntia leptocaulis	*Pencil Cholla*	Tasajillo	Cactaceae	Cactus	Obligate Upland	N
Cynodon dactylon	*Bermuda Grass*	Gallitos	Poaceae	Graminoid	Facultative Upland	I
Cyperus elegans	*Royal flatsedge*	Coquiro	Cyperaceae	Graminoid	Facultative Wetland	N
Cyperus eragrostis	*Tall flatsedge*	Sombrilla	Cyperaceae	Graminoid	Facultative Wetland	N
Cyperus involucratus	*Umbrella Plant*	Papiro Sombrilla	Cyperaceae	Graminoid	Facultative Wetland	I
Cyperus odoratus	*Fragrant flatsedge*	Hierba del Zopilote	Cyperaceae	Graminoid	Facultative Wetland	N

Cyperus sp.	*Flatsedge*		Cyperaceae	Graminoid	Facultative Wetland	
Datura wrightii	*Sacred Datura*	Toloache Sagrado	Solanaceae	Forb	Obligate Upland	N
Distichlis spicata	*Desert Saltgrass*	Huizapol	Poaceae	Graminoid	Obligate Wetland	N
Echinochloa crus-galli	*Barnyard Grass*	Pasto dentado	Poaceae	Graminoid	Facultative Wetland	I
Eleocharis geniculata	*Bent Spikerush*	Cebollin	Cyperaceae	Graminoid	Obligate Wetland	N
Eclipta prostrata	*False Daisy*	Yerba de tago	Asteraceae	Forb	Facultative	N
Encelia farinosa	*Brittlebush*	Flor de Rocio	Asteraceae	Subshrub	Obligate Upland	N
Eragrostis spectabilis	*Purple Lovegrass*	Hierba de amor purpura	Poaceae	Graminoid	Obligate Upland	N
Eragrostis pectinacea	*Tufted Lovegrass*	Hierba de amor	Poaceae	Graminoid	Facultative	N
Erigeron (Conzya) canadensis	*Horseweed*	Hierba Carnicera	Asteraceae	Graminoid	Facultative Upland	N
Eriodictyon angustifolium	*Narrowleaf Yerba Santa*	Yerba santa	Boraginaceae	Shrub	Obligate Upland	N
Eriogonum deflexum	*Skeletonweed*	Flor de Borrego	Polygonaceae	Forb	Obligate Upland	N
Erodium cicutarium	*Stork's Bill*	Aguja del Pastor	Geraniaceae	Forb	Facultative Upland	I
Eschscholzia californica	*California Poppy*	Amapola de California	Papaveraceae	Forb	Facultative Upland	N
Eucalyptus camaldulensis	*River red gum*	Eucalypto rojo	Myrtaceae	Tall Tree	Facultative	I
Euphorbia albomarginata	*Whitemargin Sandmat*	Euphorbio Blanca	Euphorbiaceae	Forb	Obligate Upland	N
Euphorbia hyssopifolia	*Hyssopleaf Sandmat*	Hierba de Pollo	Euphorbiaceae	Forb	Facultative Upland	N
Euphorbia maculata	*Spotted Spurge*	Lechosilla	Euphorbiaceae	Forb	Obligate Upland	N
Euphorbia melanadenia	*Red Gland Spurge*	Euphorbio	Euphorbiaceae	Forb	Obligate Upland	N
Euphorbia polycarpa	*Common Sandmat*	Alfombra de Arena	Euphorbiaceae	Forb	Facultative Upland	N
Eustoma exaltatum	*Catchfly Prairie Gentian*	Violeta (o Genciana De La Tierra)	Gentianaceae	Forb	Obligate Wetland	N
Festuca ovina	*Sheep's Fescue*	Barcea	Poaceae	Graminoid	Facultative Upland	I
Gentianella sp.	*Dwarf Gentians*	Flor de hielos	Gentianaceae	Forb	Facultative Wetland	N
Gilia stellata	*Star Gilia*		Polemoniaceae	Forb	Facultative Upland	N
Helianthus annuus	*Sunflower*	Girasol	Asteraceae	Forb	Facultative Upland	N

Heliotropium curassavicum	*Alkali Heliotrope*	Cola de Gama	Boraginaceae	Forb	Facultative Upland	N
Herniaria hirsuta	*Hairy Rupturewort*	Quebrantapiedras	Caryophyllaceae	Forb	Facultative Upland	N
Hordeum murinum	*Mouse Barley*	Cebadilla Ratonera	Poaceae	Graminoid	Facultative Upland	I
Hydrocotyle verticillata	*Pennywort*	Sombrerillo de agua	Araliaceae	Forb	Obligate Wetland	N
Lactuca serriola	*Milk Thistle*	Escariola Mediterránea	Asteraceae	Forb	Facultative Upland	I
Larrea tridentata	*Creosote*	Gobernadora	Zygophyllaceae	Shrub	Obligate Upland	N
Lemna minor	*Duckweed*	Lenteja de Agua	Araceae	Forb	Obligate Wetland	N
Leptochloa fusca	*Mexican Sprangletop*	Zacate Gigante Anual	Poaceae	Graminoid	Facultative Wetland	N
Linanthus bigelovii	*Bigelow's Linanthus*		Polemoniaceae	Forb	Facultative	N
Ludwigia peploides	*Floating Primrose Willow*	Duraznillo de Agua	Onagraceae	Forb	Obligate Wetland	I
Ludwigia erecta		Yerba de Jicotea	Onagraceae	Forb	Obligate Wetland	N
Lupinus sparsiflorus	*Broadleaf Lupine*		Fabaceae	Forb	Facultative Wetland	N
Lycium sp.	*Wolfberry*	Sarampion	Solanaceae	Shrub	Facultative	N
Lythrum californicum	*California Loosestrife*	Salicaria	Lythraceae	Forb	Obligate Wetland	N
Malva parviflora	*Little Mallow (Cheeseweed)*	Malva de Castilla	Malvaceae	Forb	Facultative Upland	N
Melilotus indicus	*Yellow Sweet Clover*	Trébol Amargo	Fabaceae	Forb	Facultative Upland	I
Mentzelia albicaulis	*Small Flowered Blazing Star*		Loasaceae	Forb	Facultative	N
Nicotiana glauca	*Tree tobacco*	Tabaquillo Sudamericano	Solanaceae	Shrub	Facultative	N
Nicotiana obtusifolia	*Desert tobacco*	Tabaco de Coyote	Solanaceae	Forb	Facultative Upland	N
Oncosiphon pilufer	*Globe Chamomile (Stinknet)*		Asteraceae	Forb	Facultative Upland	I
Opuntia sp.	*Prickly Pear*	Nopal	Cactaceae	Cactus	Obligate Upland	N
Parietaria hespera	*Pellitory*		Urticaceae	Forb	Facultative Upland	N
Parkinsonia aculeata	*Jerusalem Thorn*	Retama	Fabaceae	Small Tree	Facultative	N
Parkinsonia florida	*Blue Palo Verde*	Palo Verde Azul	Fabaceae	Small Tree	Obligate Upland	N
Parkinsonia microphylla	*Little Leaf Palo Verde*	Palo Verde	Fabaceae	Small Tree	Obligate Upland	N
Pectocarya platycarpa	*Broadfruit Combseed*		Boraginaceae	Forb	Facultative Upland	N

Pectocarya recurvata	*Curvenut Combseed*		Boraginaceae	Forb	Facultative Upland	N
Pennisetum setaceum	*Fountain Grass*	Zacate Africano	Poaceae	Graminoid	Facultative Upland	I
Persicaria hydropiperoides	*Swamp Smartweed*	Camaron	Polygonaceae	Forb	Obligate Wetland	N
Persicaria maculosa	*Redshank*	Cresta de Gallo	Polygonaceae	Forb	Facultative Upland	I
Phacelia distans	*Distant Scorpionweed*		Boraginaceae	Forb	Obligate Wetland	N
Phacelia crenulata	*Notch-leaf Scorpionweed*		Boraginaceae	Forb	Obligate Upland	N
Phoradendron californicum	*Mesquite Mistletoe*	Muérdago del Mezquite	Santalaceae	Subshrub	Obligate Upland	N
Plagiobothrys tenellus	*Slender Popcornflower*		Boraginaceae	Forb	Facultative Upland	N
Plagiobothrys arizonicus	*Arizona Popcornflower*	Peludilla	Boraginaceae	Forb	Facultative Wetland	N
Plantago patagonica	*Woolly Plantain*	Hierba de Santa María	Plantaginaceae	Forb	Facultative	N
Pluchea odorata	*Marsh Fleabane*	Cachanilla	Asteraceae	Forb	Facultative Wetland	N
Pluchea sericea	*Arrowweed*	Sanguinaria Europea	Asteraceae	Shrub	Facultative Wetland	N
Polygonum aviculare	*Prostrate Knotweed*	Cola de Zorra	Polygonaceae	Forb	Facultative	I
Polypogon monspeliensis	*Rabbitsfoot Grass*	Álamo	Poaceae	Graminoid	Facultative Wetland	I
Populus fremontii	*Fremont Cottonwood*	Verdolaga	Salicaceae	Tall Tree	Facultative Wetland	N
Portulaca oleracea	*Common Purslane*	Algarrobo Chileno	Portulacaceae	Forb	Facultative	I
Prosopis chilensis	*Chilean Mesquite*	Mezquite Dulce	Fabaceae	Small Tree	Facultative Upland	I
Prosopis glandulosa	*Honey Mesquite*	Mezquite Terciopelo	Fabaceae	Small Tree	Facultative Upland	N
Prosopis velutina	*Velvet Mesquite*	Mezquite Tornillo	Fabaceae	Small Tree	Facultative Upland	N
Prosopis pubescens	*Screwbean Mesquite*	Sanguinaria	Fabaceae	Small Tree	Facultative	N
Pseudognaphalium stramineum	*Cottonbatting Plant*	Higuerilla	Asteraceae	Forb	Facultative	N
Ricinus communis	*Castor Bean*	Acedera	Euphorbiaceae	Shrub	Facultative Upland	I
Rumex dentatus	*Toothed Dock*	Lengua de Vaca	Polygonaceae	Forb	Facultative Wetland	I
Salix gooddingii	*Goodingg's Willow*	Sauce Norteño	Salicaceae	Tall Tree	Facultative Wetland	N
Samolus parviflorus	*Brookweed*		Primulaceae	Forb	Obligate Wetland	N

Funastrum cynanchoides	*Dogbane/milkweed*	Bejuco de Reja	Apocynaceae	Forb	Facultative Upland	N
Schismus arabicus	*Arabian Schismus*		Poaceae	Graminoid	Obligate Upland	I
Schoenoplectus acutus	*Tule*	Tule	Cyperaceae	Graminoid	Obligate Wetland	N
Schoenoplectus americanus	*Three-Square Bulrush*	Junco Espadaña	Cyperaceae	Graminoid	Obligate Wetland	N
Schoenoplectus californicus	*California Bullrush*	Totora	Cyperaceae	Graminoid	Obligate Wetland	N
Senna covesii	*Desert Senna*	Hoja Sen	Fabaceae	Subshrub	Facultative Upland	N
Sisymbrium irio	*London Rocket*	Mostacilla	Brassicaceae	Forb	Facultative Wetland	I
Solanum elaeagnifolium	*Silverleaf Nightshade*	Pera	Solanaceae	Forb	Facultative	N
Sonchus asper	*Spiny-leaved Sowthistle*	Cerraja	Asteraceae	Forb	Facultative	I
Sonchus oleraceus	*Common Sowthistle*	Achicoria Europea	Asteraceae	Forb	Obligate Upland	I
Sporobolus sp.	*Sacaton*	Zacate	Poaceae	Graminoid	Facultative	N
Sporobolus airoides	*Alkali Sacaton*	Zacate Alcalino	Poaceae	Graminoid	Facultative	N
Stemodia durantifolia	*Purple Stemodia*	Contrayerba	Plantaginaceae	Forb	Obligate Wetland	N
Stephanomeria pauciflora	*Brownplume Wirelettuce*	Lechuga marrón	Asteraceae	Forb	Facultative	N
Stylocline micropoides	*Woolyhead Neststraw*		Asteraceae	Forb	Facultative Upland	N
Symphyotrichum expansum	*Saltmarsh Aster*	Estrella Salada	Asteraceae	Forb	Obligate Wetland	N
Tamarix chinensis	*Saltcedar*	Tamarisco	Tamaricaceae	Small Tree	Facultative	I
Tamarix ramosissima	*Saltcedar*	Tamarisco	Tamaricaceae	Small Tree	Facultative	I
Tidestromia lanuginosa	*Wooly Tidestromia*	Hierba Ceniza	Amaranthaceae	Forb	Facultative	N
Tribulus terrestris	*Puncture Vine*	Abrojo de Flor Amarilla	Zygophyllaceae	Forb	Facultative Upland	I
Typha domingensis	*Southern Cattail*	Tule	Typhaceae	Graminoid	Obligate Wetland	N
Typha latifolia	*Common Cattail*	Tule Cola de Gato	Typhaceae	Graminoid	Obligate Wetland	N
Veronica anagallis-aquatica	*Water Speedwell*	Anagálide acuática	Plantaginaceae	Forb	Obligate Wetlabd	N
Vitex agnus-castus	*Chaste Tree*	Sauce Gatillo	Lamiaceae	Small Tree	Facultative Upland	I
Vulpia octoflora = Festuca octoflora	*Sixweeks Grass*	Hierba de Seis Samanas	Poaceae	Graminoid	Obligate Upland	N
Washingtonia filifera	*California Fan Palm*	Palma Abanico	Arecaceae	Tall Tree	Facultative Wetland	N

Washingtonia robusta	*Skyduster (Mexican Fan Palm)*	Palma Blanca	Arecaceae	Tall Tree	Facultative Wetland	I
Xanthium strumarium	*Rough Cockleburr*	Abrojo	Asteraceae	Forb	Facultative	N

Ib: REPTILES AND AMPHIBIANS (HERPETOFAUNA)

Scientific binomial	**Common Name (English)**	**Nombre Común (Español)**
Anaxyrus punctatus	Red-spotted Toad	Sapo de Puntos Rojos
Anaxyrus woodhousii	Woodhouse's Toad	Sapo Chihuahuense
Apalone spinifera	Spiny Softshell	Tortuga de Concha Blanda
Aspidoscelis tigris	Tiger Whiptail	Huico Tigre del Noroeste
Aspidoscelis tigris	Tiger Whiptail	Cachora Arenera
Chrysemys picta	Painted Turtle	Tortuga Pintada
Coleonyx variegatus	Western Banded Gecko	Geco Bandeado del Noroeste
Cophosaurus texanus	Greater Earless Lizard	Lagartija Sorda Mayor
Crotalus atrox	Western Diamond-backed Rattlesnake	Cascabel de Diamantes
Dipsosaurus dorsalis	Desert Iguana	Iguana de Desierto
Hemidactylus turcicus	Mediterranean House Gecko	Geco Casero del Mediterráneo
Lampropeltis getula	Eastern Kingsnake	Falsa Coralillo Real Estadounidense
Rena (Leptotyphlops) humilis	Western Threadsnake	Culebrilla ciega de occidente
Lithobates (Rana) berlandieri	Rio Grande Leopard Frog	Rana Leopardo
Lithobates catesbeianus	American Bullfrog	Rana Toro
Masticophis (Coluber) flagellum	Coachwhip	Chicotera
Salvadora hexalepis	Western Patch-Nosed Snake	Culebra Chata
Sceloporus magister	Desert Spiny Lizard	Lagartija Espinosa del Desierto
Thamnophis marcianus	Checkered Gartersnake	Sochuate
Trachemys scripta	Pond Slider	Tortuga Gravada
Urosaurus graciosus	Long-tailed Brush Lizard	Lagartija de Árbol del Noroeste
Urosaurus ornatus	Ornate Tree Lizard	Lagartija de Árbol Norteña
Uta stansburiana	Common Side-blotched Lizard	Lagartija de Mancha Lateral Norteña

Ic: BIRDS

Scientific binomial	**Common Name (English)**	**Nombre Común (Español)**	**Code**	**Habitat Preference Guild**
Melozone aberti	Abert's Towhee	Rascador Enmascarado	ABTO	Riparian-obligate

Anas carolinensis	American green-winged teal	Cerceta Americana	AGWT	Marsh - obligate
Fulica americana	American Coot	Gallareta Americana	AMCO	Marsh - obligate
Falco sparverius	American Kestrel	Cernícalo Americano	AMKE	Generalist
Calypte anna	Anna's Hummingbird	Colibrí Cabeza Roja	ANHU	Riparian - facultative
Anthus rubescens	American pipit	Bisbita Norteamericana	AMPI	Woodland - facultative
Turdus migratorius	American Robin	Mirlo Primavera	AMRO	Generalist
Mareca americana	American Wigeon	Pato Chalcuán	AMWI	Marsh - obligate
Myiarchus cinerascens	Ash-throated Flycatcher	Papamoscas Garganta Ceniza	ATFL	Generalist
Setophaga auduboni	Audubon's Warbler	Chipe de Audubon	AUWA	Woodland - obligate
Pelecanus erythrorhynchos	American White Pelican	Pelícano Blanco Americano	AWPE	Aquatic
Haliaeetus leucocephalus	Bald Eagle	Águila Cabeza Blanca	BAEA	Riparian - facultative
Tyto alba	Barn Owl	Lechuza de Campanario	BANO	Generalist
Hirundo rustica	Barn Swallow	Golondrina Tijereta	BARS	Generalist/Urban
Myiarchus tyrannulus	Brown-crested Flycatcher	Papamoscas Gritón	BCFL	Riparian - facultative
Archilochus alexandri	Black-chinned Hummingbird	Colibrí Barba Negra	BCHU	Riparian - facultative
Nycticorax nycticorax	Black-crowned Night Heron	Garza Nocturna Corona Negra	BCNH	Marsh - facultative
Megaceryle alcyon	Belted Kingfisher	Martín Pescador Norteño	BEKI	Riparian - facultative
Vireo bellii	Bell's Vireo	Vireo de Bell	BEVI	Riparian-obligate
Thryomanes bewickii	Bewick's Wren	Saltapared Cola Larga	BEWR	Woodland - facultative
Polioptila caerulea	Blue-gray Gnatcatcher	Perlita Azulgrís	BGGN	Woodland -facultative
Molothrus ater	Brown-headed Cowbird	Tordo Cabeza Café	BHCO	Sonoran upland
Pheucticus melanocephalus	Black-headed Grosbeak	Picogordo Tigrillo	BHGR	Woodland
Passerina caerulea	Blue Grosbeak	Picogordo Azul	BLGR	Riparian - facultative
Sayornis nigricans	Black Phoebe	Papamoscas Negro	BLPH	Sonoran upland
Coragyps atratus	Black Vulture	Zopilote Común	BLVU	Sonoran upland
Himantopus mexicanus	Black-necked Stilt	Monjita Americana	BNST	Marsh - facultative
Polioptila melanura	Black-tailed Gnatcatcher	Perlita del Desierto	BTGN	Sonoran upland
Amphispiza bilineata	Black-throated Sparrow	Zacatonero Garganta Negra	BTSP	Sonoran upland
Setophaga nigrescens	Black-throated Gray Warbler	Chipe Negrogrís	BTYW	Woodland - facultative
Icterus bullockii	Bullock's Oriole	Calandria Cejas Naranjas	BUOR	Riparian - facultative

Selasphorus platycercus	Broad-tailed Hummingbird	Zumbador Cola Ancha	BTAH	Woodland
Campylorhynchus brunneicapillus	Cactus wren	Matraca del Desierto	CACW	Sonoran upland
Branta canadensis	Canada Goose	Ganso Canadiense Mayor	CANG	Generalist
Melozone fusca	Canyon Towhee	Rascador Viejita	CANT	Sonoran upland
Vireo cassinii	Cassin's Vireo	Vireo de Cassin	CAVI	Woodland - obligate
Toxostoma curvirostre	Curve-billed Thrasher	Cuicacoche Pico Curvo	CBTH	Sonoran upland
Spizella passerina	Chipping Sparrow	Gorrión Cejas Blancas	CHSP	Woodland - facultative
Petrochelidon pyrrhonota	Cliff Swallow	Golondrina Risquera	CLSW	Riparian - facultative
Gallinula galeata	Common Gallinule	Gallineta Frente Roja	COGA	Marsh - obligate
Accipiter cooperii	Cooper's Hawk	Gavilán de Cooper	COHA	Riparian - facultative
Calypte costae	Costa's Hummingbird	Colibrí Cabeza Violeta	COHU	Sonoran upland
Mergus merganser	Common Merganser	Mergo Mayor	COME	Marsh - obligate
Corvus corax	Common Raven	Cuervo Común	CORA	Generalist
Geothlypis trichas	Common Yellowthroat	Mascarita Común	COYE	Riparian-obligate
Toxostoma crissale	Crissal Thrasher	Cuicacoche Crisal	CRTH	Riparian - facultative
Phalacrocorax auritus	Double-crested Cormorant	Cormorán Orejón	DCCO	Marsh - facultative
Junco hyemalis	Dark Eyed-Junco	Junco Ojos Negros	DEJU	Woodland - obligate
Empidonax oberholseri/hammondii	Dusky/Hammond's Flycatcher	Papamoscas Matorralero/de Hammond	DUFL/HAFL	Woodland
Streptopelia decaocto	Eurasian Collared-Dove	Paloma Turca de Collar	EUCD	Urban
Sturnus vulgaris	European Starling	Estornino Pinto Eurasiático	EUST	Urban
Mareca strepera	Gadwall	Pato Friso	GADW	Marsh - obligate
Callipepla gambelii	Gambel's Quail	Codorniz de Gambel	GAQU	Generalist
Ardea herodias	Great Blue Heron	Garza Morena	GBHE	Riparian - facultative
Colaptes chrysoides	Gilded Flicker	Carpintero de Pechera del Noroeste	GIFL	Sonoran upland
Melanerpes uropygialis	Gila Woodpecker	Carpintero del Desierto	GIWO	Sonoran upland
Ardea alba	Great Egret	Garza Blanca	GREG	Riparian - facultative
Empidonax wrightii	Gray Flycatcher	Papamoscas Bajacolita	GRFL	Woodland - obligate
Butorides virescens	Green Heron	Garcita Verde	GRHE	Riparian - facultative
Geococcyx californianus	Greater Roadrunner	Correcaminos Norteño	GRRO	Sonoran upland
Vireo vicinior	Gray Vireo	Vireo Gris	GRVI	Woodland

Tringa melanoleuca	Greater Yellowlegs	Patamarilla Mayor	GRYE	Marsh - obligate
Quiscalus mexicanus	Great-tailed Grackle	Zanate Mayor	GTGR	Urban
Pipilo chlorurus	Green-tailed Towhee	Rascador Cola Verde	GTTO	Woodland - facultative
Parabuteo unicinctus	Harris's Hawk	Aguililla Rojinegra	HASH	Sonoran upland
Catharus guttatus	Hermit Thrush	Zorzal Cola Canela	HETH	Woodland - obligate
Setophaga occidentalis	Hermit Warbler	Chipe Cabeza Amarilla	HEWA	Woodland - obligate
Haemorhous mexicanus	House Finch	Pinzón Mexicano	HOFI	Riparian - facultative
Eremophila alpestris	Horned Lark	Alondra Cornuda	HOLA	Upland
Icterus cucullatus	Hooded Oriole	Calandria Dorso Negro Menor	HOOR	Riparian-obligate
Passer domesticus	House Sparrow	Gorrión Doméstico	HOSP	Urban
Troglodytes aedon	House Wren	Saltapared Común	HOWR	Riparian-facultative
Vireo huttoni	Hutton's Vireo	Vireo Reyezuelo	HUVI	Riparian-facultative
Columbina inca	Inca Dove	Tortolita Cola Larga	INDO	Urban
Charadrius vociferus	Killdeer	Chorlo Tildío	KILL	Urban
Chondestes grammacus	Lark Sparrow	Gorrión Arlequín	LASP	Grassland/upland/woodland
Passerina amoena	Lazuli Bunting	Colorín Pecho Canela	LAZB	Riparian - facultative
Picoides scalaris	Ladder-backed Woodpecker	Carpintero Mexicano	LBWO	Generalist
Ixobrychus exilis	Least Bittern	Avetoro Menor	LEBI	Marsh - obligate
Spinus psaltria	Lesser Goldfinch	Jilguerito Dominico	LEGO	Riparian - facultative
Chordeiles acutipennis	Lesser Nighthawk	Chotacabras Menor	LENI	Sonoran upland
Calidris minutilla	Least Sandpiper	Playero Diminuto	LESA	Aquatic
Melospiza lincolnii	Lincoln's Sparrow	Gorrión de Lincoln	LISP	Riparian - facultative
Lanius ludovicianus	Loggerhead Shrike	Verdugo Americano	LOSH	Sonoran upland
Oreothlypis luciae	Lucy's Warbler	Chipe Rabadilla Castaña	LUWA	Riparian - facultative
Anas platyrhynchos	Mallard	Pato Norteño	MALL	Marsh - obligate
Cistothorus palustris	Marsh Wren	Saltapared Pantanero	MAWR	Marsh - obligate
Geothlypis tolmiei	MacGillivray's Warbler	Chipe Lores Negros	MGWA	Riparian - obligate
Zenaida macroura	Mourning Dove	Huilota Común	MODO	Generalist
Phalacrocorax brasilianus	Neotropic Cormorant	Cormorán Neotropical	NECO	Riparian - facultative
Cardinalis cardinalis	Northern Cardinal	Cardenal Rojo	NOCA	Riparian - facultative
Colaptes auratus	Northern Flicker	Carpintero de Pechera Común	NOFL	Woodland - facultative
Circus hudsonius	Northern Harrier	Gavilán Rastrero	NOHA	Marsh - facultative

Mimus polyglottos	Northern Mockingbird	Centzontle Norteño o ruiseñor	NOMO	Generalist
Stelgidopteryx serripennis	Northern Rough-winged Swallow	Golondrina Alas Aserradas	NRWS	Marsh - obligate
Spatula clypeata	Northern Shoveler	Pato Cucharón Norteño	NSHO	Marsh - obligate
Oreothlypis celata	Orange-crowned Warbler	Chipe Oliváceo	OCWA	Woodland - obligate
Pandion haliaetus	Osprey	Águila Pescadora	OSPR	Marsh - facultative
Podilymbus podiceps	Pied-billed Grebe	Zambullidor Pico Grueso	PBGR	Marsh - obligate
Falco peregrinus	Peregrine Falcon	Halcón Peregrino	PEFA	Woodland - facultative
Phainopepla nitens	Phainopepla	Capulinero Negro	PHAI	Riparian - facultative
Spinus pinus	Pine Siskin	Jilguerito Pinero	PISI	Woodland - obligate
Vireo plumbeus	Plumbeous Vireo	Vireo Plomizo	PLVI	Woodland - obligate
Regulus calendula	Ruby-crowned Kinglet	Reyezuelo Matraquita	RCKI	Woodland - facultative
Agapornis roseicollis	Rosy-faced Lovebird	Periquito de Namibia	RFLO	Urban
Aythya collaris	Ring-necked Duck	Pato Pico Anillado	RNDU	Marsh - obligate
Sphyrapicus nuchalis	Red-naped Sapsucker	Carpintero Nuca Roja	RNSA	Woodland - facultative
Columba livia	Rock Pigeon	Paloma Doméstica	ROPI	Urban
Salpinctes obsoletus	Rock Wren	Saltapared de Rocas	ROWR	Sonoran upland
Buteo lineatus	Red-shouldered Hawk	Aguililla Pecho Rojo	RSHA	Riparian - obligate
Buteo jamaicensis	Red-tailed Hawk	Aguililla Cola Roja	RTHA	Generalist
Agelaius phoeniceus	Red-winged Blackbird	Tordo Sargento	RWBL	Marsh - obligate
Sayornis saya	Say's Phoebe	Papamoscas Llanero	SAPH	Generalist
Passerculus sandwichensis	Savanna Sparrow	Gorrión Sabanero	SAVS	Upland/Grassland
Egretta thula	Snowy Egret	Garza Dedos Dorados	SNEG	Marsh - facultative
Melospiza melodia	Song Sparrow	Gorrión Cantor	SOSP	Riparian - facultative
Porzana carolina	Sora	Polluela Sora	SORA	Marsh - obligate
Actitis macularius	Spotted Sandpiper	Playero Alzacolita	SPSA	Marsh - facultative
Pipilo maculatus	Spotted Towhee	Rascador Moteado	SPTO	Woodland - obligate
Anser caerulescens	Snow Goose	Ganso Blanco	SNGO	Marsh - obligate
Accipiter striatus	Sharp-shinned Hawk	Gavilán Pecho Canela	SSHA	Woodland - obligate
Piranga rubra	Summer Tanager	Piranga Roja	SUTA	Riparian - obligate
Setophaga townsendi	Townsend's Warbler	Chipe de Townsend	TOWA	Woodland - facultative
Cathartes aura	Turkey Vulture	Zopilote Aura	TUVU	Generalist
Pyrocephalus obscurus	Vermilion Flycatcher	Papamoscas Cardenalito	VEFL	Riparian - facultative

Auriparus flaviceps	Verdin	Baloncillo	VERD	Riparian - facultative
Vireo gilvus	Warbling Vireo	Vireo Gorjeador	WAVI	Woodland - facultative
Zonotrichia leucophrys	White-crowned Sparrow	Gorrión Corona Blanca	WCSP	Woodland - facultative
Sialia mexicana	Western Bluebird	Azulejo Garganta Azul	WEBL	Woodland - obligate
Tyrannus verticalis	Western Kingbird	Tirano Pálido	WEKI	Generalist
Sturnella neglecta	Western Meadowlark	Pradero del Oeste	WEME	Sonoran upland
Piranga ludoviciana	Western Tanager	Piranga Capucha Roja	WETA	Woodland - obligate
Contopus sordidulus	Western Wood-Pewee	Papamoscas del Oeste	WEWP	Woodland - facultative
Plegadis chihi	White-faced Ibis	Ibis Ojos Rojos	WFIB	Marsh - obligate
Gallinago delicata	Wilson's Snipe	Agachona Norteamericana	WISA	Marsh - obligate
Cardellina pusilla	Wilson's Warbler	Chipe Corona Negra	WIWA	Riparian - facultative
Aeronautes saxatalis	White-throated Swift	Vencejo Pecho Blanco	WTSW	Sonoran upland
Zenaida asiatica	White-winged Dove	Paloma Alas Blancas	WWDO	Riparian - facultative
Icteria virens	Yellow-breasted Chat	Chipe Grande	YBCH	Riparian - obligate
Setophaga petechia	Yellow Warbler	Chipe Amarillo	YEWA	Riparian-obligate
Xanthocephalus xanthocephalus	Yellow-headed Blackbird	Tordo Cabeza Amarilla	YHBL	Marsh - facultative
Setophaga coronata	Yellow-rumped Warbler	Chipe Rabadilla Amarilla	YRWA	Woodland - obligate

Appendix II: Sampling Methods and Effort

IIa: Plant Surveys

Year	Seasons Surveyed	Sampling Effort (Number of Plots Sampled)
2012	3: Spring, Hot Dry, Hot Wet	210 (90 per site)
2022	3: Spring, Hot Dry, Hot Wet	210 (90 per site)

IIb: Herpetofauna Surveys

Year	Seasons Surveyed	Sampling Effort (Number of Plots Surveyed)
2012	2: Spring, Hot Dry	54 (18 per site)
2013	4: Spring, Hot Dry, Monsoon, Post-Monsoon	108 (36 per site)
2014	3: Spring, Hot Dry, Post-Monsoon	81 (27 per site)
2015	3: Spring, Hot Dry, Post-Monsoon	81 (27 per site)
2016	3: Spring, Hot Dry, Post-Monsoon	81 (27 per site)
2017	3: Spring, Hot Dry, Post-Monsoon	81 (27 per site)
2018	3: Spring, Hot Dry, Post-Monsoon	81 (27 per site)
2019	3: Spring, Hot Dry, Post-Monsoon	81 (27 per site)
2020	2: Hot Dry, Post-Monsoon	54 (18 per site)
2021	1: Post-Monsoon	27 (9 per site)
2022	3: Spring, Hot Dry, Post-Monsoon	81 (27 per site)

IIc: Bird Surveys

Year	Seasons Surveyed	Sampling Effort (Number of Points Sampled)
2014	4: Winter, Spring, Hot Dry, Post-Monsoon	96 (24 per site)
2015	4: Winter, Spring, Hot Dry, Post-Monsoon	96 (24 per site)
2016	3: Winter, Spring, Hot Dry	54 (18 per site)
2017	4: Winter, Spring, Hot Dry, Post-Monsoon	96 (24 per site)
2018	4: Winter, Spring, Hot Dry, Post-Monsoon	96 (24 per site)
2019	4: Winter, Spring, Hot Dry, Post-Monsoon	96 (24 per site)
2020	3: Winter, Hot Dry, Post-Monsoon	54 (18 per site)
2021	3: Winter, Spring, Hot Dry	54 (18 per site)
2022	4: Winter, Spring, Hot Dry, Post-Monsoon	96 (24 per site)