Accidental and Restored Wetlands of the Lower Salt River:

A Portrait of Biodiversity and Community Composition

Over a Decade of Urbanization

by

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ABSTRACT

Urban wetland ecosystems provide myriad ecosystem services and are shaped by diverse social and ecological factors. In rapidly urbanizing parts of the desert Southwest, wetlands are especially vital. Across less than 60 km as it enters the Phoenix area, the Salt River is dammed, diverted, re-filled, clear-cut, restored, and ignored. This study documents how animal and plant communities in three perennially inundated reaches of the river changed over a decade under different social-ecological pressures. One wetland in the urban core is restored, another formed accidentally by human infrastructure, and the last is managed on the urban periphery. Surveys conducted since 2012 used point-count surveys to assess bird communities and visual encounter surveys to assess reptiles and amphibians. Plant communities were surveyed in 2012 and 2022 using cover classes. Between 2012 and 2022, accidental and restored wetlands close to the urban core displayed an increase in plant abundance, largely consisting of introduced species. While all sites saw an increase in plant species considered invasive by land management groups, both urban wetlands saw an increase in regionally native species, including plants that are culturally significant to local Indigenous groups. Reptile communities declined in richness and abundance in both urban sites, but birds grew in abundance and richness at the urban restored site while not changing at the urban accidental wetland. The non-urban site saw stable populations of both birds and herpetofauna. These trends in biotic communities reveal ecological tradeoffs under different management strategies for urban wetlands. These findings also create a portrait of wetland communities along a rapidly urbanizing arid river. As the Salt River watershed becomes more urbanized, it is important to establish a more empathetic and informed relationship between its plant and

animal—including human—residents. To this end, these data were incorporated in a series of handmade paper artworks, crafted from the most abundant wetland plant species found at the study sites, harvested alongside local land management efforts. These artworks examine the potential of four common cosmopolitan wetland plants for papermaking, revealing the potential to align ecosystem management efforts with both materials production and fine arts. By using relief printmaking to visualize long-term ecological data, I explored an alternative, more creative and embodied way to engage with and visualize urban wetland communities. This alternate mode of engagement can complement ecological management and research to diversify disciplines and participants engaged with understanding and living alongside urban wetlands.

DEDICATION

I dedicate this work to the many people who have supported me through this research, including family, friends, colleagues, and mentors. In particular, I dedicate it to the memory of Gregg Haller (1954-2019), whose friendship and mentorship pushed me to think about the ways art and science intersect and complement each other.

ACKNOWLEDGMENTS

I acknowledge that ASU and all Salt River Biodiversity Project case study sites are located within the traditional and contemporary lands of the Akimel O'Odham and Piipaash peoples, whose long-standing relationship with On'k Akimel (the Salt River) is much deeper than that of Western ecological knowledge. I pay respect to tribal members and elders who have cared for these landscapes in the past, present, and into the future.

I also acknowledge that the forced, unpaid labor of generations of Black Americans is the foundation of American wealth. I am indebted to these historical laborers, as well as workers worldwide who continue to be exploited for the creation of tools and materials we use every day.

I thank the formal land managers of the study sites (Salt River Pima-Maricopa Indian Community, City of Phoenix, Audubon Society, City of Mesa, and US Forest Service) for allowing our team to conduct research there, and I extend these thanks to the sites' informal managers: the community of South Phoenix, the Salt River Pima-Maricopa Indian Community, and those living in the bed of the Salt River itself for welcoming us into their spaces.

Finally, this research would not be possible without the labor of a decade of dedicated researchers with the Central Arizona-Phoenix Long Term Ecological Research program, or the help of dozens of volunteers. Thank you for your assistance, expertise, thoughts, and companionship.

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

Figure		Page

1. Background

1.1 Urban Wetlands as Social-Ecological Systems

Urban wetland ecosystems provide myriad ecosystem services (Bolund and Hunhammar 1999), including habitat corridors (Bateman et al. 2015, Stromberg et al. 2016, Andrade et al. 2018), heat mitigation and shelter for individuals without shelter (Palta et al. 2016), flood mitigation (Zedler & Kircher 2005), contaminant removal (Handler et al. 2016, Palta), water quality mitigation and management (Childers 2020, Treese et al. 2020), cultural importance for Indigenous groups such as the Akimel O'Odham (SRPMIC 2022), and denitrification (Suchy 2016, Suchy et al. 2020). Despite this importance, wetlands in urban areas have often been reduced or replaced by human development, altering the structure of wetland mosaics and jeopardizing the species and processes in these ecosystems (Gibbs 2000). A network of social, ecological, and technological factors and inputs shape urban wetland ecosystems, including stormwater infrastructure (Palta et al. 2017), species introductions (Ehrenfeld 2008, McKinney 2006), and direct human use (Palta et al. 2016). Understanding the dynamics of these factors requires an examination of urban wetlands in the context of larger urban ecosystems.

Globally, urban areas are becoming both geographically larger as well as home to larger human populations and growing communities of other animals, fungi, and plants. The discipline of urban ecology emerged as an attempt to understand how cities function as unique ecosystems rather than as simply built environments. The term "urban ecology" has been used for nearly a century, but much early work focused on plants and nonhuman animals within urban spaces (Matheson 1944), or how cities as a "detritus ecosystem" made up primarily of one species can have large downstream effects on other ecosystems (Stearns 1970). Contemporary urban ecological work is shifting away from this kind of an ecology *in* cities to focus on an ecology *of*, *for,* and *with* cities (Ramalho et al. 2012, Childers et al. 2015, McPhearson et al. 2016). This requires acknowledging the critical role humans play as keystone species of urban ecosystems who can drive major ecosystem processes and change, for better or worse. (Childers et al. 2015).

As keystone species, human interactions with and exertions of power over wetlands can have implications for ecosystem services and functions, including the well-being of human, plant, and wildlife communities (Gibbs 2001, Jenkins et al. 2003, Larsen et al. 2013, Ballut-Dajud et al. 2022). For most of human history, river management efforts have focused on modifying wetland ecosystems for human well-being and economic growth, especially within Western practices of ecology and engineering (Ballut-Dajud et al. 2022). Yet during the same century, scientists, land managers, traditional ecological knowledge holders, policy makers, and artists have increasingly called to rehabilitate landscapes—including efforts as small scale and artistic as Mel Chin's Reclamation Field (Chin, 1991-present) and as ambitious as the global scale policy goals of the UN Decade of Ecosystem Restoration (United Nations, 2020). Many of the practices adopted for managing wetland ecosystems for combined human and more-than-human wellbeing are relatively new, which requires long term research and engagement to understand the long-term results of different management strategies for biotic communities.

One way humans shape urban ecosystems is by our design and management choices for Urban Ecological Infrastructure (UEI). Urban Ecological Infrastructure refers to any component of the urban fabric that contributes to ecological structure and function, from potted plants to public parks (Childers et al. 2019, Brown et al. 2020). Urban spaces contain many forms of UEI, which may be discussed in terms of color: Green spaces (parks, gardens, yards, etc.) and gray spaces (buildings, roads, etc.) are most often discussed, but other kinds of UEI, including blue (bodies of water), turquoise (wetlands), and brown (bare earth) are just as vital for urban ecosystems (Childers et al. 2019). This study examined changes in biotic communities within three case studies of turquoise UEI in Central Arizona, an increasingly urbanizing, hot, and arid region.

Across less than 60 kilometers, as it passes through the Phoenix Area, the Salt River (On'k Akimel) is dammed, diverted, re-filled, clear-cut, restored, and ignored. On'k Akimel is the ancestral home of the Akimel O'Odham people and many native Sonoran Desert plant and animal species. More recently it is home to countless newcomers, including cosmopolitan plants, a swelling population of feral horses, high-rise apartment complexes, and growing communities of people living without shelter. Since the Salt River is one of the few waterways in the arid Phoenix valley where water is often a limiting resource, its role is particularly central to the urban ecosystem. It has been diverted into canals by various inhabitants for centuries, but beginning in 1903 the Salt River Project began an ambitious series of projects to fully "reclaim" On'k Akimel's water (Gooch et al. 2007). Seven dams were built on the river, flooding canyons to create reservoirs holding more than 2.3-million-acre feet (2.800 billion cubic meters) of water and diverting almost all flowing Salt and Verde River water into canals (Gooch et al. 2007). Originally, this water was primarily used for agriculture, but in the last century this has shifted to include ever-growing urban uses (Gooch et al. 2007, Larsen et al. 2013). While Salt River water has been redistributed to flow through the city's canals, lawns, and bathroom pipes, it rarely flows through its original course.

These dams and diversions prevent the Salt River from ecologically or hydrologically being a river through most of its urban extent. However, in some places, novel water sources create patches of marsh and riparian gallery forest in the riverbed (Bateman et al. 2014). Some of these are remnant wetlands, others formed from urban runoff, and others were restored by land managers in response to growing calls for rehabilitating ecosystems. These patches of wetland and riparian forests that grow in the Salt River bed provide elements of all four categories of ecosystem services: cultural, provisioning, regulating, and supporting.

1.1.1. CULTURAL ECOSYSTEM SERVICES:

Many cultural disservices are associated with urban wetlands of the Salt River (Brown et al. 2020), including unpleasant odors, aesthetics, and pest organisms such as mosquitoes (Elser et al. 2019). However, the Salt River provides many cultural services, which are often difficult to quantify or commodify (du Bray 2019). The growing population of regional urban dwellers use the river to recreate, including biking or running along paths in the Rio Salado Restoration area to tubing or kayaking the Salt River in Tonto National Forest. Tempe Town Lake is visited by 2.4 million people each year, making it the second-most visited park in Arizona (City of Tempe), illustrating the cultural importance of the river to present-day Arizonans. Its cultural significance runs even deeper for the Akimel O'Odham or Pima people. The Akimel O'Odham are a contemporary Indigenous group descended from the ancient Hohokam peoples, who built an extensive system of canals irrigating 110,000 acres of urban and agricultural development roughly seven hundred years ago (Waters and Ravesloot 2001, Howard 2003). This system of canals is the basis for most of contemporary water infrastructure, and On'k Akimel remains a central part of Akimel O'Odham culture.

1.1.2. PROVISIONING SERVICES

The Hohokam canals represent one of the earliest known examples of provisioning services provided by the Salt River. The river provided water for irrigation, making agricultural and urban development in the valley viable. Salt River ecosystems also provided sustenance (both fish and edible plants) as well as crafting materials for the Hohokam and later Akimel O'Odham peoples, who still harvest culturally important plants including u'us kokomagĭ (*Pluchea sericea,* arrow weed) and che'ul (*Salix gooddingii,* Goodding's willow) from the river. While fewer people rely on On'k Akimel as a source of food and materials now than in the pre-European past, many people experiencing homelessness have established informal settlements along the river and harvest both plants and fish from the ecosystem for use in construction or for consumption (Palta et al. 2016). The Salt River is also used for electricity generation, providing around 700 GWh a year using the dams along the river and canal system (SRP 2022).

1.1.3. REGULATING SERVICES

The wetland ecosystems along the Salt River also provide regulating services, including flood mitigation (Zedler & Kircher 2005), contaminant removal (Handler et al. 2016, Palta et al. 2015), water quality mitigation and management (Childers 2020, Treese et al.. 2020), carbon sequestration (Mitsch et al. 2013), and denitrification (Suchy, 2016, Suchy et al. 2020). In addition to these large-scale services that help regulate the wider system, urban wetlands, including riparian shade trees, provide substantial heat mitigation. In a hot dry region, this service is crucial to the wellbeing of human (Palta et al. 2016), plant, and animal (Bateman et al. 2015) communities living along and in the river.

1.1.4. SUPPORTING SERVICES

Human and more-than-human communities also benefit from supporting services provided by urban wetland and riparian ecosystems, including isolation from some forms of disturbance common in cities. Informal settlements built in urban wetland and riparian areas benefit from many ecosystem services, such as heat mitigation and seclusion from urban pressures such as law enforcement that are more common in other urban areas (Palta et al. 2016). For wildlife, urban riparian ecosystems function as a habitat corridor through the heart of an otherwise hazardous city (Hofer et al. 2010, Bateman et al. 2014), providing habitat connectivity, resource availability, and species dispersal.

1.2. Press-Pulse Dynamics of Urban Salt River Wetlands

Different presses and pulses from the environment surrounding urban wetlands result in diverse outcomes including altered community structure and composition (Gibbs 2000), which in turn can change ecosystem functions and the provision of services (LaRue et al. 2023). In order to understand the complex processes involved in coupled social-ecological systems, researchers have used a variety of conceptual models. One such model, put forward in Collins et al. 2011 (Figure 1) frames social-ecological systems as two templates– social and biophysical– that are shaped by each other and by external drivers. The social template exerts consistent, long-term presses, as well as concentrated and sudden pulses on the biophysical template, which in turn provide ecosystem services and disservices for the social template. Examining long-term interactions of social and biophysical aspects of urban ecosystems through these Press-Pulse Dynamics (PPD) reveals processes at work in complex social-ecological systems (Kominoski et al. 2018). For example, a management decision to divert a river's flow could lead to shifts in plant communities from marsh sedges and flood tolerant Cottonwoods to more species that are tolerant of dry conditions, such as

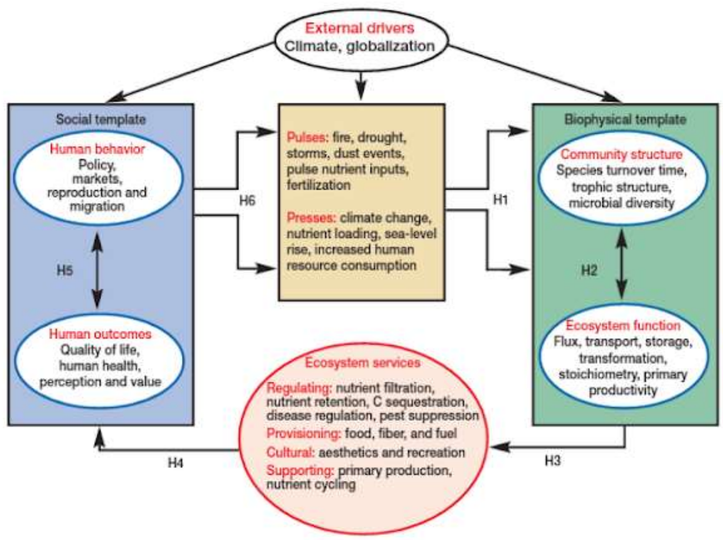

Figure 1: Press-Pulse Diagram from Collins et al. 2011 displaying links between social and biophysical aspects of a system.

Saltcedar and Buffelgrass. In turn, these new communities may offer different ecosystem services and disservices, including increased vulnerability to fire and reduced heat mitigation, which in turn shape human lives and choices.

Figure 2 is a Press-Pulse Dynamics model I developed to characterize urban wetland ecosystems of the Salt River (Figure 2). The different sites studied in this research experience exert different presses and pulses, revealing a unique dynamic between social and ecological components at each of the sites. This study focused on community composition and biodiversity of urban Salt River wetlands, so the scope is mostly limited to the right side of this conceptual framework, specifically investigating

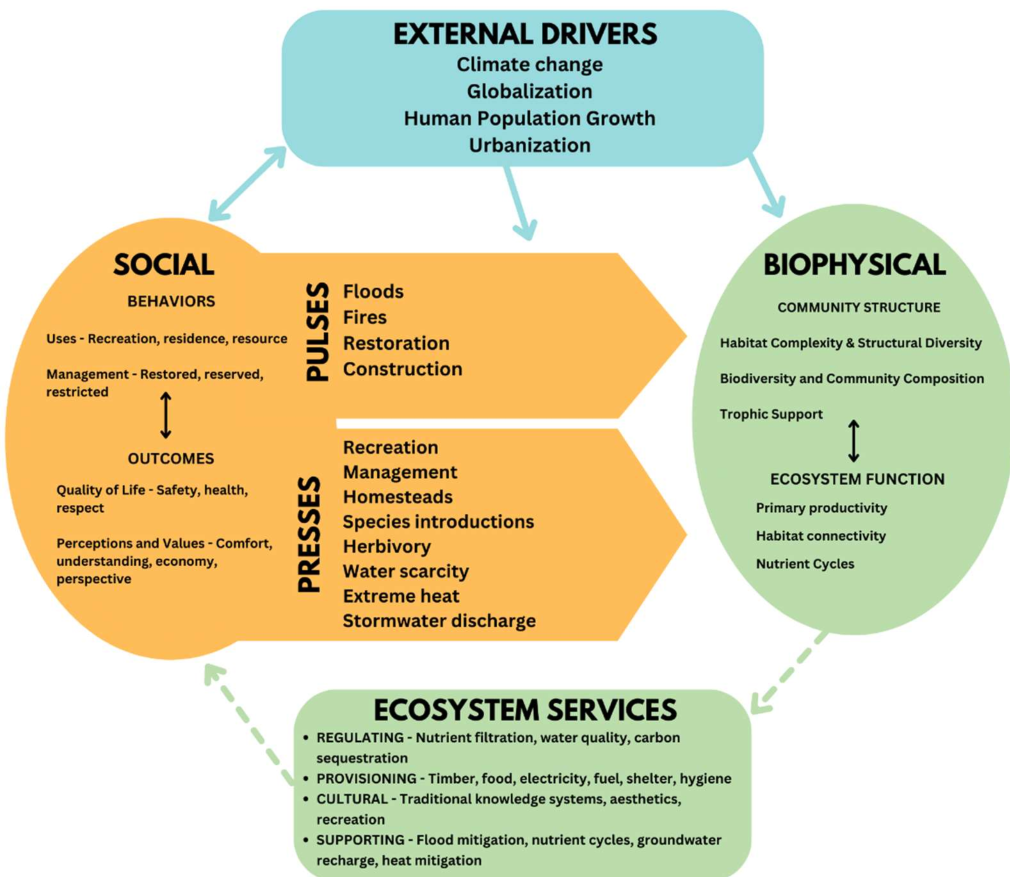

Figure 2: Press Pulse Diagram of the Salt River Wetland Social-Ecological System, highlighting particular presses and pulses from the social template, as well as specific services provided by the biophysical template. In this study, I focus mostly on the top half of the Biophysical template, examining Community Structure.

changes in community structure (within the biophysical template). This research also investigated potential provisioning and cultural ecosystem services by integrating experimental papermaking techniques. Each ecosystem provides a unique network of services and disservices (Sala et al. 2017, Sala 2016) which are shaped by the biophysical template, so the discussion below summarizes several presses that particularly affect the biotic communities of the urban Salt River.

One press that is explicitly observable in community composition studies in urban ecosystems is the arrival and establishment of non-native species. Urban wetlands and riparian areas are susceptible to the establishment of introduced species due to increased interaction with human landscape horticulture, increased disturbance, and controlled hydrology (Ehrenfeld 2008, Catford et al. 2011). The dispersal and establishment of both intentionally and unintentionally introduced species in a time of rapid globalization and urbanization has contributed to the phenomenon of global biotic homogenization (McKinney et al. 2006, Padullés Cubino et al. 2019, Cubino et al. 2020). This means cities around the world are becoming more biotically similar to each other and less like the surrounding ecosystem (McKinney et al. 2006), as well as more functionally homogenous (Cubino et al. 2020).

The arrival of introduced species can have a range of impacts for ecosystems. Some introduced species remain localized, while others become widely established (Colautti et al. 2004). Many riparian and wetland species from around the world have established populations in the urban Salt River, but many native species, well adapted to the harsh conditions of the Sonoran Desert, have remained the most abundant in the area. This combination of species creates a mosaic of cosmopolitan plant communities that retains a distinct regional signature (Stromberg et al. 2015), providing habitat for native and non-native animal species. Introduced plant and animal species can shape the services and disservices ecosystems provide (Chapin III 2000, Ehrenfeld 2003). Established populations of introduced species may destabilize ecosystems through pressures such as increased herbivory or predation (Montijo 2002, Luck et al. 2003, Burkle 2012), such as in the case of the American Bullfrog (*Lithobates catesbeiana*) which is both a voracious carnivore and vector for the spread of fungal diseases which contribute to global declines in amphibian population (Garner et al. 2006) Yet in other cases, introduced species may stabilize or even bolster ecosystem function and services. For instance, rapid expansions of grasses into arid shrubland can increase carbon storage and denitrification (Wolkovich et al. 2010), especially in novel or highly disturbed ecosystems, such as many urban ecosystems (Simberloff and Von Halle 1999, Hobbs et al. 2009). In addition, once a species with invasive traits is established, it is difficult and costly to manage, and virtually impossible to eliminate (Wittenberg and Cock 2005). Conservative estimates show roughly 20% of invasive species removal projects lead to unintended negative consequences for ecosystems (Prior et al. 2018). Ecosystems facing regular anthropogenic disturbance, such as urban rivers, are especially prone to experience negative outcomes following invasive species removal (Prior et al. 2018) due to severe disturbance from removal processes, susceptibility to re-invasion from non-target species, or because trophic webs depend on non-native species in novel ecosystems (Hobbs et al. 2009).

This variability means it is important to move beyond a simplistic dichotomy of native and nonnative species (Thompson et al. 1995, Chew 2010) and towards a more comprehensive understanding of the processes to which species contribute (Colautti et al. 2004) and how species traits interact within the biotic and abiotic structure (Verberk 2013). A shift away from biogeographical categorization to one based on functional traits would allow land managers to better understand the effects of species traits highlights how changes in community composition on larger ecological dynamics, including complex networks of tradeoffs among ecosystem services and disservices (Chapin III et al. 2000 Verberk 2013, Sala 2016, Sala et al. 2017).

Pressures such as species introductions and management can also shape ecosystem functions, including habitat complexity and structure. Diverse vegetation structure and composition is a key component of complex habitats, which in turn support diverse animal communities (Cubley et al. 2020, Bateman & Merritt 2020) as well as more stable ecosystem function (LaRue et al. 2023), greater productivity, and increased resilience to stochastic events (Tilman et al. 2014, Mitchell et al. 2023). Vegetation structure is influenced by not only climate and topographic factors, but also by regional species pools and life histories of plant species, as well as legacy effects from historical human land uses, which can be complex in urban systems (Fukami 2015, Mitchell et al. 2023).

Long-term monitoring of community composition is critical to understanding, managing, and predicting shifts in ecosystems, especially when land managers are seeking to understand the success (or consequences) of their efforts (Bunting et al. 2021). The Salt River is heavily managed, modified, and urbanized, and long-term monitoring of changes in its biotic communities will contribute to more effective adaptive management (Bunting et al.). This paper synthesizes ten years of data describing biotic communities of the urban Salt River collected by the Central Arizona-Phoenix Long Term Ecological Research Program (CAP) to answer the following research questions: *How have wetland communities of plants, birds, and herpetofauna (reptiles, and amphibians) along the Salt River changed over a decade of urbanization and management?* In particular*, how have wetland plant communities changed, and how might those changes shape habitat structure in urban Salt River wetlands?*

1.3 *Exploring Plant Community Composition Through Art*

The Salt River supports a sizable diversity of plant species, but a comparatively small number of graminoids and trees make up most of many communities. These monotypic stands of *Typha spp.* (Cattail) and *Arundo donax* (Giant Reed), and scrubby forests of *Prosopis spp.* (Mesquite) and *Tamarix spp.* (Saltcedar) play many crucial roles in ecosystem (dis)functions and (dis)services. These cosmopolitan species are frequently the target of costly and time-intensive removal efforts, including those by the City of Phoenix and City of Tempe, who were clearing vegetation in or near the research sites discussed in this study. I worked with land managers to use *Typha, Arundo, Schoenoplectus, Salix, Prosopis,* and *Tamarix* they had cleared from the study sites to investigate their potential for manual papermaking.

These abundant plants are the functional foundation for plant and animal communities of the Salt River, so I experimented with manual papermaking techniques to produce large sheets of paper from the harvested plants that were used for artistic data visualizations of each site (See Results and Discussion). By engaging with these plants in such a direct physical way, I have activated a more embodied and artistic way of learning about and from them in the spirit of growing calls for integrations of ecological art and science (Nabhan 2004, Kimmerer 2013, Brown 2014, National Academy of Sciences and Engineering 2018, Heras et al. 2021). I used these combined perspectives to gain a greater understanding of and appreciation for the physical structure of these plants and their habits as living organisms. In addition, I used the paper made from these species to mount voucher specimens of each species. I displayed these data visualization art pieces as part of my thesis defense and in the exhibit galleries at the Nina Mason Pulliam Audubon Center at the Rio Salado site. These hand-printed artworks are an exploration of how to communicate data in a novel format that might engage different ways of thinking and knowing for both academic and public viewers.

2 METHODS

2.1 The Salt River Biodiversity Project

The Salt River Biodiversity Project (SRBP) is an effort to understand how novel ecosystems emerging in urban reaches of On'k Akimel have changed over time. Conducted by the Central Arizona-Phoenix Long Term Ecological Research program (CAP LTER), the project began in 2012. It surveys the composition of plant, bird, reptile, and amphibian communities in seven study sites in different reaches of the Salt River along a gradient of urbanization (Bateman et al. 2014, Bateman and Childers 2021). Study sites include accidental wetlands, seasonally flooded washes, restored areas, dry reaches, and managed recreational areas that represent the diverse management styles implemented along the urbanized Salt River.

2.1.1 SRBP SURVEY METHODS

All three taxa (plants, birds, and herpetofauna) were surveyed along three transects at each site, spaced approximately 150 m apart. The endpoints of transects were determined in 2012 by observing geomorphic and vegetative shifts from wetland to upland species, meaning transects range in length from 125-400 m. Plots were selected in a stratified random order to obtain a sample representative of shifts across a range from marsh to rocky upland. The transect endpoints and sample plots have not moved since 2012, though there are gaps in datasets due to high flows and informal settlements in study plots. Keeping transect endpoints consistent allows the data to track shifts in where vegetative transitions occur.

CAP LTER has conducted bird and herpetofauna surveys continuously since 2012 (Bateman and Childers 2022). Vegetation surveys were conducted at the beginning of the project in 2012, but were not resurveyed each year. I re-surveyed vegetation at three of the seven sites in 2022 to assess differences in the plant communities after ten years (see Section 3).

2.1.1.1 Bird Surveys

Birds were surveyed seasonally—winter migration season, spring pre-monsoon, and late summer post-monsoon—at two stations per transect (six per site). A trained observer visited each station for a 15-minute point-count survey, recording all birds seen and heard. Surveys were conducted within four hours of sunrise and on days with low wind (0-3 on a Beaufort scale); observers identified and classified species according to Sibley (2000) and Pyle and DeSante (2012). Bird abundance was calculated as the greatest number of individuals of a species seen at once at only one of two transect stations to reduce likelihood of recording the same bird twice. Methods changed in 2014 from a 10-minute point count to a 15-minute point count, so here I only included the 2014-2022 data (Bateman 2016).

2.1.1.2 Reptile and Amphibian Surveys

Reptiles and amphibians, or herpetofauna, were assessed in nine 10 x 20 m^2 plots per site–three distributed along each transect–using visual encounter surveys. Since herpetofauna are more active in warm climatic conditions, surveys were conducted on warm, sunny days with little wind in spring, summer dry season, and summer wet season. Summer surveys were occasionally conducted on partly cloudy days since the ambient temperature is warmer and herpetofauna are still active. Surveys began after sunrise once temperatures passed 70° F and rocks and pavement were warm to the touch.

Observers scanned plots through binoculars and then walked the length of the transect, each monitoring a 5 m wide half of the plot for any reptiles seen or flushed by carefully moving vegetation and debris with hiking poles. These methods are most effective for the observation of lizards, so while snakes and anurans are reported, these data do not fully represent all reptiles and amphibians. Herpetofaunal abundance was recorded as the greatest number of individuals observed per species on each transect (up, mid, and downstream) in any given year. This accounts for different frequencies of sampling (such as during the COVID-19 pandemic). Observers identified and classified species using Brennan and Holycross (2009) and Crother (2008).

2.1.1.3 Vegetation Surveys

Vegetation sampling was conducted in 2012 to assess habitat on each of the SRBP transects. In 2022, I reconducted these surveys at a subset of SRBP sites (see 2.2, *Site Description*) using the same methods as in 2012 (Bateman et al. 2014) to examine changes in botanical communities after a decade of urban pressures. I assessed thirty 2 m^2 plots (one square meter on each side of the transect) distributed across each transect.

Plots were first visually assessed for soil or sediment traits (silt, sand, gravel, or cobble), water level, and litter (herbaceous, woody, and human) and then for species abundance using cover classes. Plants in each plot were identified to species where possible, using Kearney and Peebles (1960), *Vascular Plants of Arizona* (1994-2022), SEINet Portal Network (2023), and *Jepson eFlora* (2013-2022), and voucher specimens were collected for most species. Species classified as culturally important by the Salt River Pima Maricopa Indian Community's Department of Cultural and Natural Resources (Denoted with an asterisk * in Appendix B) were not collected but were photographed in the field for identification. Plants were surveyed in the spring (March), the summer dry season (June), and the summer monsoon season (September) to capture seasonal variation.

Figure 3. Study sites: Tonto, a managed remnant wetland (Left); Price, an accidental wetland, (Mid); and Rio Salado, a restored wetland (Right).

2.2 Site Description

In arid ecosystems, urban or otherwise, regular water availability is key for supporting ecosystem services (Handler and Suchy 2022, Suchy et al. 2020, Andrade et al. 2018, Razgour et al. 2018, Palta et al. 2017, Palta et al. 2016, Skujiņš 1981), including habitat provision and biodiversity, on which SRBP focuses. In this study, I examined biotic communities at three sites along the urban Salt River across the ten years of SRBP. All three sites (shown in Figure 3) are in reaches of the river with water in at least some of the channel year-round, though each has a different degree of urbanization and management.

2.2.1 TONTO

This reach (hereafter referred to as "Tonto") is located in Tonto National Forest, upstream of the Granite Reef Diversion Dam and about 5 miles from the closest municipal boundary. This site, shown in figure 4, is managed by the US Forest Service (USFS) and is protected from development but still shaped by various human activities. Its hydrology is regulated by the Stewart Mountain Dam, managed by the Salt River Project to create and maintain Saguaro Reservoir. A Flood Control District of Maricopa County rain gauge at this dam recorded 18.8 cm of rain in 2012 and 24.51 cm in 2022 (Maricopa County 2023). Annual precipitation was reported as the sum of 108 days prior to September 30 to record monsoon season, and 108 days prior to January 31 to record the smaller winter wet season.

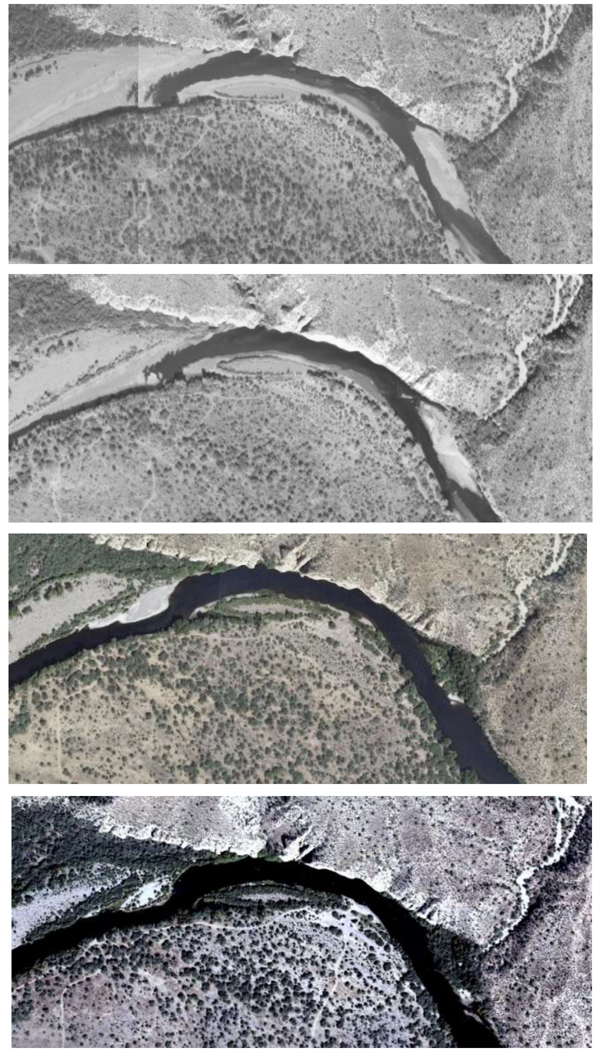

Figure 4. Tonto study reach from the air. Top to bottom: 1991, 2001, 2011, 2021. (Maricopa County, 2023)

In addition to rainfall, water is supplied to this reach by regulated releases from the Stewart Mountain Dam in response to downstream demands from urban areas for water and power generation. This water is usually released in higher quantities during summer months, creating a pattern of high flow in summer and low flow in winter that lead to both inundation and drying out of the riparian zone.

This part of the river is used for recreation year-round, including by nature enthusiasts, hikers, equestrians, kayakers, and anglers; these activities represent a press on the reach's more-than-human community. Also, between May and September, tubing becomes a popular activity for Arizonans attempting to escape the extreme summer heat. Thousands of tubers float through this stretch each year, smashing into stands of *Typha* and *Arundo*, and generating a particular kind of litter, including flip flops, beer cans, vape pens, sunglasses, and marshmallows (throwing puffy jumbo marshmallows at each other while tubing has become a local tradition). These marshmallows are eaten by raccoons, grackles, fish, and horses.

The growing herds of feral horses (*Equus ferus caballus*) in this part of Tonto are another important press on the ecosystem. Some say they descended from the horses of Spanish conquistadors, others that they escaped from ranchers, and some Indigenous communities say the horses predate colonization. In any case, opinions on their management also vary. Some conservationists are concerned about the impact of such a

Figure 5. Horses crossing the Salt River in March 2022. On this day I recorded 68 horses over four miles of the Salt River.

large grazing herbivore on the native plants and animals that inhabit the Sonoran Desert (Norris 2018). In particular, overgrazing in riparian areas could threaten critical habitat for the Southwestern Willow-Flycatcher (*Empidonax traillii extimus*), an endangered bird species that nests in the region, including in several refugia on the Salt River within Tonto National Forest (USFWS 2023). The US federal government currently responds to this concern with regular round-ups of horses to keep herds to a manageable size. Yet some horse advocates oppose this system of management, saying these captures are inhumane (Hunold and Britton 2022). Even with these controversial management methods in place, herds are growing; wild horses were uncommon in the area in 2012 and now large herds are present year-round. For example, on one day of data collection for SRBP in March 2022 (shown in figure 5), I counted 68 horses in 4 miles of the river. The horses eat terrestrial and aquatic vegetation, as well as piles of hay brought in by unmarked pickup trucks. They present pressures of grazing and trampling for flora, but also potential dispersal opportunities for propagules of plants that are well-adapted to grazing.

2.2.2 PRICE

The Price site, downstream of Tonto, referred to as an accidental wetland (Bateman et al. 2014, Palta et al. 2016, Suchy 2016), is located around and beneath the intersection of Arizona State Routes 101 and 202 at the intersection of Mesa, Tempe, and the Salt River Pima Maricopa Indian Community (SRPMIC). The water at Price is supplied by several novel sources including storm drains, effluent from wastewater treatment, and runoff from agricultural irrigation and highways. Much of this water comes through the Price Rd. stormwater outfall, providing a perennial source of water to sustain this wetland. A rain gauge at the Price storm drain recorded 17.72 cm of rain in 2012, and 13.59 cm in 2022 (Maricopa County 2023).

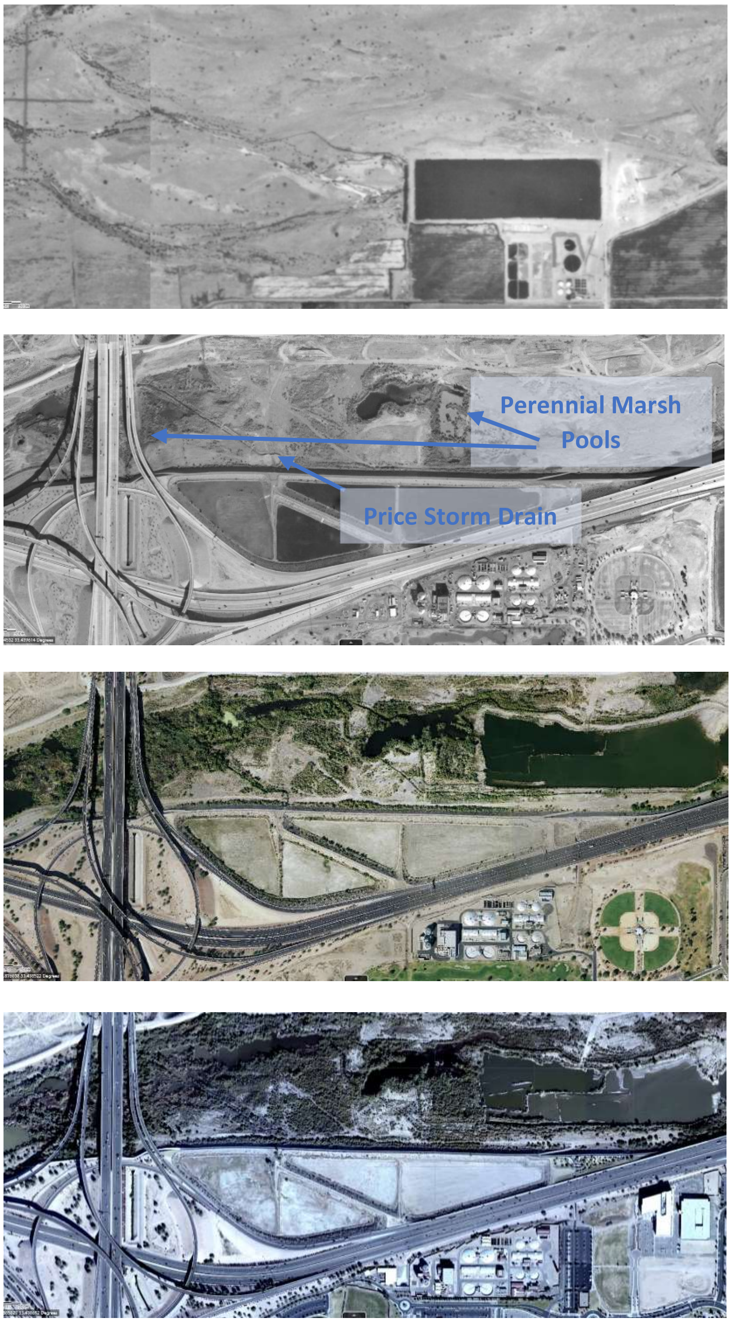

Figure 6: Price study site, top to bottom: 1991, 2001, 2011, 2021 (Maricopa County 2023)

The bed of the Salt River was a perennial river for millennia until the late 1930s, after which it has been dry except for seasonal rains. The marsh wetlands at Price emerged after relatively recent infrastructure changes. The first aerial photograph in Figure 6 (top) shows the site in 1991, without any water, though it did seasonally flood. On the lower right of the photo, you can see the Mesa Northwest Water Reclamation Plant, which treats wastewater and then pumps it into underground aquifers as part of the Granite Reef Underground Water

Storage Project (City of Mesa 2023). Following the installation of the AZ 202 Red Mountain highway, completed in 2008, water began accumulating in pools, as shown in the second photo, from 2001. Ten years later, in 2011, this water had accumulated enough to sustain sizeable patches of marsh year-round. This is around the time the SRBP began sampling this site, and the water and vegetation has continued to accumulate in the ten years since, as seen in the final photo, from 2021.

The Price site is not formally managed or regulated but is home to people who have established sizable informal settlements over the years (Palta et al. 2016), despite periodic intervention by law enforcement and occasional floods. This reach of the river is surrounded by a variety of urban and suburban land uses including agricultural and industrial development to the north, residential, commercial, retail, and entertainment areas to the south, and transit infrastructure directly overhead. All these neighboring parcels are sources of both presses and pulses for the site. This system is occasionally flooded by upstream releases of water from the Granite Reef Diversion Dam, but also by stormwater runoff from nearby impermeable surfaces such as parking lots and highways that is concentrated at the Price Rd. stormwater outfall. As the surrounding areas urbanize further, these stormwater pulses will likely be larger and more intense. This water brings nutrients, contaminants, and plant propagules (including ornamental and agricultural species) into the ecosystem. The combination of urban factors with a lack of formal management makes this reach an example of how a novel urban wetland ecosystem may develop in a relatively short time and with little or no intervention.

2.2.3 RIO SALADO (RIO)

The Rio Salado Habitat Restoration Area, downstream from Price, is an 8 km stretch of the Salt River rehabilitated by the City of Phoenix and the US Army Corps of Engineers. The $100+ million restoration project was proposed in 1996 (US Army Corps of Engineers, 1996), five years after the first photo in Figure 7, which shows the river as a dumping ground with scattered vegetation. The Army Corps of Engineers' restoration efforts were completed in 2005 (DeSemple 2006). This project entailed the construction of terraces, native tree plantings, and the installation of a groundwater system to supply water to several wetlands and irrigated terraces, in turn maintaining a low flow of water in the river channel, which is seasonally supplemented by storm drain outflows. Two nearby rain gauges (Roeser Rd. in South Mountain Village and Jackson St. in Central City)

Figure 7: Rio Salado study area, top to bottom: 1991, 2001, 2011, 2021 (Maricopa County 2023)

monitor stormwater channels that drain into the Rio Salado Restoration Area; they recorded a mean 11.05 cm of monsoon rain in 2012 and 9.96 cm in 2022 (Maricopa County 2023).

The City of Phoenix manages the area through irrigation, species removal, plantings, litter removal, and partnerships with local wildlife groups such as Audubon Southwest and Liberty Wildlife. The restoration area also provides recreation opportunities, aesthetic experiences, construction materials, and food for nearby residents, culturally important plants for local Indigenous groups, and vital shade and water for people living without shelter. The frequent use of this ecosystem for all these purposes is also an important form of management pressing on this ecosystem. Rio Salado is surrounded by dense urban development, including transit infrastructure, a garden and interpretive center, and a superfund site, as well as commercial, residential, and industrial development.

Figure 8. Rio Salado after restoration construction and planting in 2006 (DeSemple 2006).

2.3 *Data Analysis*

Plants, birds, and herpetofauna were surveyed in different seasons and using different protocols, so I analyzed all three taxa by examining annual means. Site means and totals were compared to data from previous years for each site and for all three sites combined, but because so many factors vary among these sites, data were not statistically analyzed across sites. All taxa were examined for overall abundance and richness, and then assessed by species, guild, or characteristics to further reveal shifts in community composition.

2.3.1 ANIMAL COMMUNITY ANALYSIS

Reptiles and amphibians were analyzed in two ways: 1) by examining annual totals for species richness and abundance for each year; and 2) by abundance of each species per year. Annual abundance for each species was classified as the maximum number seen in one observation on each transect of the site for each year. Reptiles and amphibians were also assessed for native species, to understand what portion of the community at each site was made up of introduced species. All herpetofauna observed had a conservation status of Least Concern, so no analysis was performed on conservation status or rarity.

I analyzed bird observations for combined total abundance and species richness at the site level for 2014-2022; changes in sampling protocols prohibited the use of 2012 and 2013 data. I also categorized and analyzed the bird data by habitat preferences (obligate or facultative riparian, marsh, upland, woodland, urban, or generalist) according to the *Arizona Breeding Birds Atlas* (Corman and Wise-Gervais 2005) and Cubley et al. 2020.

2.3.2 PLANT COMMUNITY ANALYSIS

I analyzed vegetation data most thoroughly because of the crucial role plants play as the base of trophic energetics and as essential components of ecosystem structure and functions. I analyzed vegetation data for overall species richness using species accumulation curves—total encountered species in each successive plot—and abundance using annual means of each species' percent cover at each site. I also used the Shannon Diversity Index (Shannon 1948, Clarke and Warwick 2001, Magurran 2004) to weigh both richness and abundance. The SDI takes the proportion of an entire sample that is a single species, multiplies it by its own natural logarithm, and repeats this for every species in a sample. The absolute value of the sum of these results is a number between 1.5 and 3.5, with a higher value representing a more diverse community.

Then I examined community composition at the species and genus level by categorizing plants by growth habit, wetland indicator status, biogeographical range, management policy (such as invasive), and cultural importance. This helped reveal shifts in community structure and the success of management efforts aimed at native species conservation. The total annual percent cover of each of these categories was then compared between 2012 and 2022. Each category is discussed in further detail below.

To understand changes in the habitat plants provide for animals (including humans), I categorized plants by their physical structure and growth habit. Graminoids are grass-like plants including true grasses (family *Poaceae*) and many marsh plants such as sedges (Cyperaceae), rushes (Juncaceae), and cattails (Typhaceae). Herbaceous, non-graminoid plants make up the forbs and herbs category. Cacti are the smallest group and contains only members of the *Cactaceae* family, distinguished by their succulent stems studded with spines. Cacti display a unique abundance and diversity in the study region but due to their preference for dry upland habitats were present usually only on the upslope margins. The remaining groups are woody and characterized by their average height at maturity. Woody species less than 1m in mature height were classified as subshrubs, and shrubs ranged from 1 to 3m. Plants taller than 3m were considered trees, with those that grow to less than 10m in height considered small trees, and those over 10m considered tall trees.

I also classified plants according to their USDA wetland indicator status (USDA 2023)–obligate wetland to facultative to obligate upland–to help understand landscape shifts since the study began. In 2012, transect endpoints were placed where the plant community transitions to upland species, the driest category of USDA wetland indicator, so the extent to which these upland plants extend into (or do not appear) along transects can suggest patterns in surface and groundwater availability at the sites (Baird et al. 2005).

Many, if not all, land managers in an age of rapid species introductions and extinctions are concerned with opportunistic new arrivals, often labeled invasive or pernicious. Introduced plant species are most often targeted because of their ease of detection and role as foundations of trophic webs. While opinions vary on the legitimacy of such distinctions in an urban landscape totally transformed by human activity (Stromberg et al. 2007, Stromberg et al. 2009, Chew and Hamilton 2010), the abundance of introduced species is often used as an indicator of conservation success or failure in urban areas. The three study reaches of the Salt River are managed by different entities: the US Forest Service, the Salt River Pima-Maricopa Indian Community, and the City of

Phoenix, and each has different lists of species designated as “weeds,” “prohibited,” and/or “invasive.” Data from each site were analyzed for the presence of such unwelcome species according to the list of each site-specific land management group in an attempt to understand the efficacy of eradication and/or control of targeted species. Native plants were also distinguished to assess the success of native plant conservation and planting efforts.

In a tightly coupled social-ecological system such as an urban wetland facing near constant interaction with humans, it is important to also examine the cultural ecosystem services provided by wetland plant communities. Cultural ecosystem services are difficult to quantify or assess because assessment requires sociological, anthropological, or ethnobotanical expertise. Several reaches of the Salt River are managed by the Salt River Pima Maricopa Indian Community, a nation consisting of the Akimel O’Odham and Piipash peoples. Traditional Ecological Knowledge built by the Akimel O’Odham and Piipaash over centuries in relation to On’k Akimel is long-term ecological research of the river, and with the right investments of time and resources for co-creating ecological priorities and practices for management, Indigenous and Western knowledges can complement each other (Nelson 2018, Nelson & Vucetich 2018). The Salt River Pima-Maricopa Indian Community’s Natural and Cultural Resources Department prohibits the collection of culturally significant plants when conducting ecological surveys, and CAP LTER was provided with a list of these species. Out of respect for tribal data sovereignty, I did not discuss any specific cultural uses or roles of these plants in this paper, but I did include the category of “Cultural Importance” for analysis. This reveals how some plants that have long occupied the area in a relationship with the Akimel

O'Odham and Piipash peoples are becoming more or less abundant in the face of contemporary urbanization.

2.4 Data Visualization Through Art

This portion of the study investigated a potential provisioning ecosystem service of urban wetland plants through experimental papermaking. Biomass from select plant species was harvested to make paper. *Arundo donax, Schoenoplectus californicus,* and *Typha latifolia* tissues were harvested from the Rio Salado site with the help of City of Phoenix staff and community partners as part of continued maintenance of storm drains within the restoration area. *Prosopis velutina, Salix goodingii,* and *Tamarix chinensis* tissues were harvested near the Price site by the City of Tempe as part of a wetland clearing project, ostensibly a public safety initiative, where the City is thinning vegetation in the Salt River bed to only 37 trees per hectare, with no emergent herbaceous vegetation remaining.

Arundo donax has been previously studied for its potential for commercial kraft papermaking (Shatalov and Pereira 2002, Raposo Oliveira Garcez 2022). Some small companies, such as Arundo Bioenergy based in Hungary, are taking advantage of the

Figure 9: Soaking, steaming, and cooking Arundo donax *to soften fibers.*

plant's high biomass yield and near global distribution as a source for paper products and energy generation (Arundo Bioenergy 2021). *Typha* sp. has also been studied for its use in papermaking (Jahan et al. 2007), but it is not commonly used commercially. However, many hand papermakers use it for art and craft purposes. *Tamarix* and *Prosopis* have been less commonly used, though *Prosopis* pods have been used in some art and craft papermaking. Research investigating the potential of *Prosopis* fibers for paper making–commonly considered invasive weeds in East Africa, where these studies have been conducted–yielded contradictory results, ranging from little value (Khristova 2009) to suitable (Muhammad et al. 2019). *Schoenoplectus* and *Salix* have many traditional uses, but neither has been explored as a material for paper. This study furthers explores papermaking with these six abundant cosmopolitan wetland plants.

Each genus of plant and type of tissue required a different amount of time for cooking or beating (preparation details for each type of fiber are in Results and Discussion.), but all essentially followed the same basic steps. The plants were cut, and then field retted (dried in the sun) for several weeks to allow the tissues to dry out and local decomposers to harvest what they need–and in the process begin to break down fibers. One half kilogram of dry plant tissue was broken into 3-5 cm pieces and soaked in water overnight (Fig. 9). The biomass was then steamed for up to an hour (Fig. 9) and, if necessary, peeled to separate the cellulose-rich bast tissues between outer bark layers and the woody core. *Typha* seed heads and leaves, *Schoenoplectus* stems, and *Arundo* leaves did not require this bast-stripping step. Plant fibers were then cooked in a solution of soda ash and boiling water for 4-21 hours (depending on the fiber), maintaining a pH of 10-11 (Fig. 9). Once the biomass had cooked down to soft, easily separable fibers, they were rinsed (Fig. 10), trimmed to 2 cm in length, and macerated in a Hollander beater using a graduated weight sequence over 3.5-6 hours (Fig. 10). Once the pulp was fully macerated, consistently suspended, and tested at a neutral pH, it was transferred to a vat. A mold and deckle box (Fig. 11) were used to pull suspended pulp fibers from the vat, forming a sheet (Fig. 11). This sheet of paper was pressed in a hydraulic press with 680 kg of pressure for half an hour and then 910 kg for ten minutes, after which the sheet was dried in a ventilated dryer box under 18 kg of pressure for at least four days.

Each study site was represented by two sheets of paper, one from one of the most abundant marsh species in 2012, and one from one the most abundant marsh species in 2022 (see Table 1). All three marsh graminoids grow in monotypic stands and play

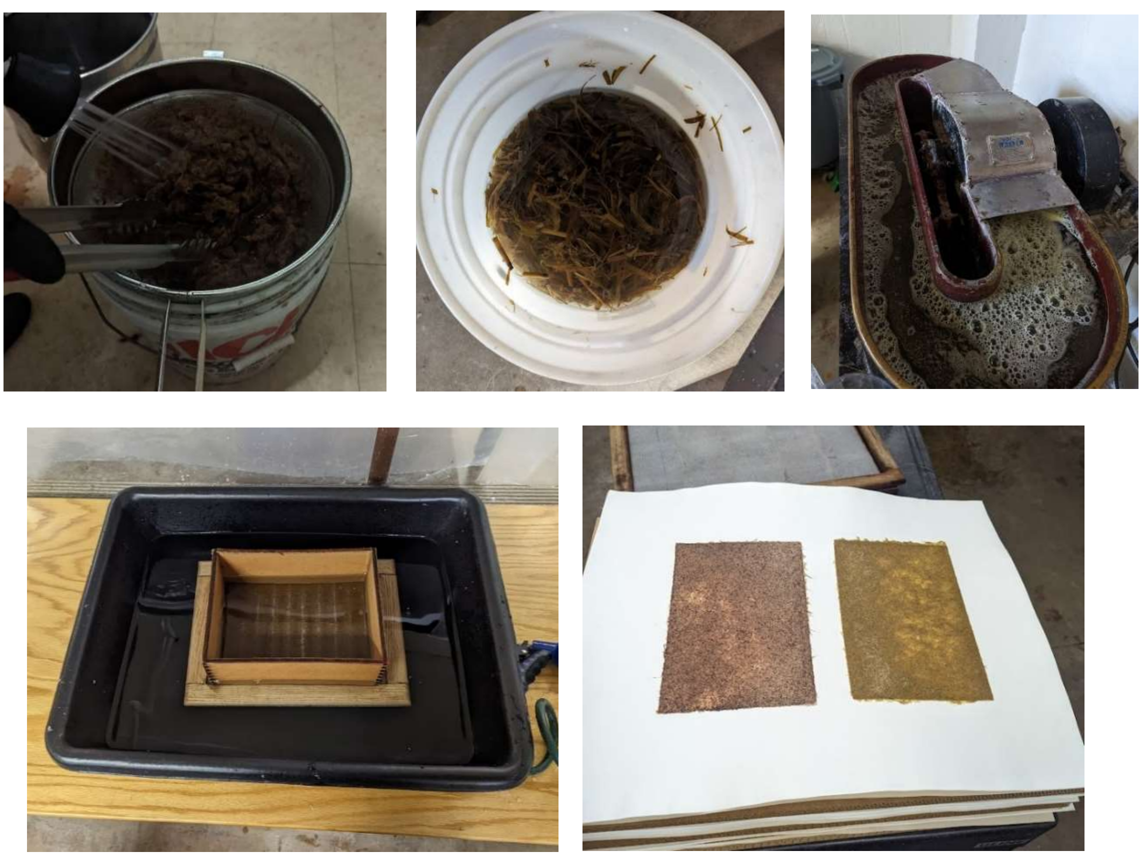

Figure 10: Rinsing, resoaking, and beating fibers with a Hollander beater (top). A mold and deckle for pulling sheets and pulled sheets of Typha *and* Arundo *before pressing and drying (bottom)*

important roles in habitat provision, water quality, and nutrient cycling, so I used them to represent the foundation of plant communities at the three sites in 2012 and 2022. On each sheet, I created a chart to represent the plant community of each site, with small hand-carved relief printed symbols acting as pixels to represent 1% annual cover of a given category of plant used for analysis (wetland indicator status, cultural significance, habitat structure, etc.). These pixels are shown in Figure 11. I tiled the pixels to create a visual representation of the plant community composition of each site. Images of these data visualizations are included in the Results section below, were displayed at my thesis defense, and were part of redesigned interpretive exhibits at the Nina Mason Pulliam Rio Salado Audubon Center.

I also pulled standard herbarium-size sheets of paper from the pulp of each species. These were tested for a neutral pH and then used to mount and catalog voucher specimens of each species from this study. These vouchers, along with other specimen collections from this research, were donated to the Arizona State University Vascular Plant Herbarium.

Figure 11: Hand carved linoleum blocks for relief printing (left) and prints of each "pixel," representing 1% cover of a classification of plants (right). The image on the right functions as a key for charts presented in Section 3.2: Site-Specific Results. The top two rows represent the growth form of the plant, the middle row displays wetland indicator status (wavy lines indicating obligate wetland species and diagonal lines indicating obligate upland. The diamond with a crossed arrow and Arrow Weed branch represents culturally important Species, the location pin denotes native species and the X indicates a prohibited species (according to land managers for each respective site). These pixels were printed in an orientation that mirrors the Social and Biophysical Templates of the Press Pulse Diagram in Figure 2, as shown below. Socially determined factors (Prohibited, Culturally Important, and Native) are on the left, and Growth Form, which is determined by the physical biology of plants, is on the right. Wetland Indicator Status is in the center because it reflects ecological factors but is determined by a political body (the US Department of Agriculture).

Socially determined Biophysically determined

3. RESULTS AND DISCUSSION

I divided the results of this study into three sections. First (3.1), I reviewed bird, herptile, and plant data for all three sites combined to show changes happening across the Lower Salt River system as a whole. I examined abundance and species richness over consecutive years for animals; I analyzed 2012 and 2022 vegetation data using percent cover, species richness (species accumulation curves), and the Shannon Diversity Index. Then (3.2), I examined each site in detail to reveal trends within biotic communities of each separate site. I classified herptiles by species and birds by habitat preference to how populations of these groups changed over consecutive years, and I also discuss several species that are particularly abundant. I examined vegetation communities by abundance and according to several different classifications, such as growth form and wetland indicator status (see Section 2.3 Data Analysis). I portrayed shifts within these different categories of plants by hand printing charts using relief blocks on handmade paper (Figures 17, 20, and 22). The results section (3.3) discussed the results of experiments in manual papermaking from four abundant wetland species found in Salt River ecosystems, including specific methods used to create the artworks I presented in section 3.2.

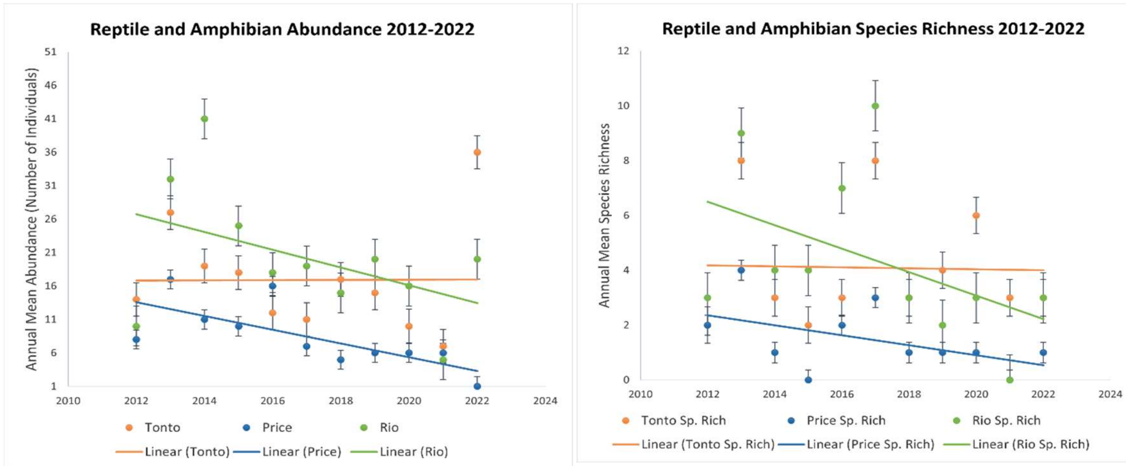

Figure 12 Abundance and Species Richness of herpetofauna at all three sites 2012-2022. Error bars are standard error.

3.1 SRBP RESULTS OVERVIEW

Overall, long-term data from SRBP point to several trends in this group of connected ecosystems. Survey results suggest a decline in herpetofauna abundance at all sites combined, with a more rapid decline in abundance at the urban sites than the peri-urban site, which revealed no change in abundance (Figure 12a). Species richness declined significantly across years for all sites ($p=0.0003$) and again suggests these declines are driven by decreasing richness in urban sites, with no change at Tonto (Figure 12b). The observed decrease in herpetofauna could be a result of decreased visibility at the urban sites, where plant communities have become denser since 2012 (as discussed below). However, this decline is also consistent with research on the vulnerability of some herpetofauna communities to the pressures of urbanization, such as lower water availability, worse water quality, feral cats, and motorized vehicles (Andrews et al. 2008, Todd et al. 2010, French et al. 2018, How et al. 2022). Furthermore, Central Arizona is an extremely hot region, and becoming hotter due to climate change and the urban heat island effect (Golden 2004). Ectotherms are especially sensitive to climactic conditions

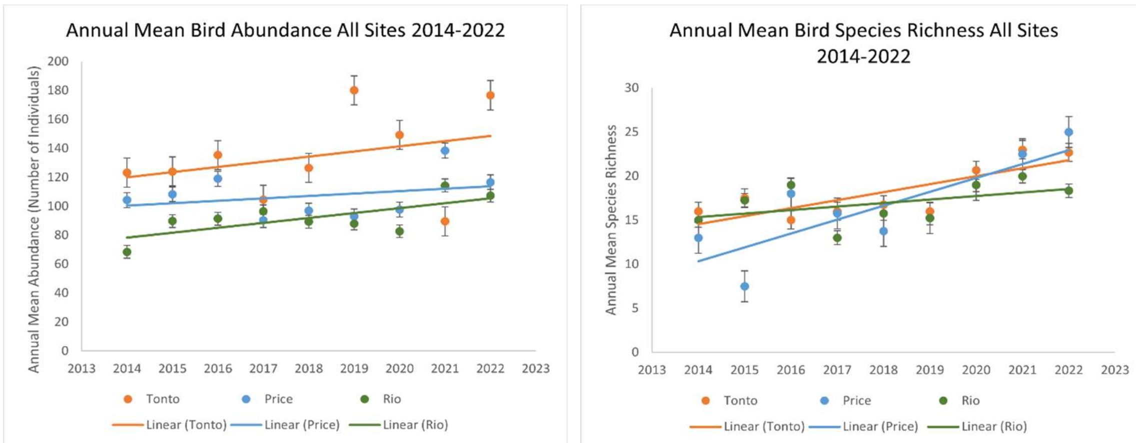

Figure 13: Bird Abundance and Species Richness for all sites (Annual Means) from 2014-2022. Error bars are standard error.

such as temperature and moisture, so increased heat from climate and the urban heat island could be fatal for some reptiles and amphibians, especially those already living in hot regions (Duarte et al. 2012). However, some urban-adapted reptile and amphibian species persist and thrive in cities (Hamer and Macdonnell 2010), and some species, including several species of geckos and frogs, were detected at the urban sites but not at Tonto, demonstrating their ability to adapt to urban habitats. Bird communities revealed a different trend (Figure 13), with species richness increasing across all sites combined (p=0.006). Combined abundance did not significantly increase, but no sites showed a decrease in bird abundance, and abundance did significantly increase at Rio Salado (see Section 3.2.3).

Plant abundance for all sites combined was significantly higher in 2022 than 2012 (p=0.032), largely because of an increase in the abundance of several opportunistic species at the urban study sites, such as *Tamarix chinensis* (22.75% cover at Price in 2012, 77.58% in 2022)*, Salix gooddingii (*8.67% cover of Rio in 2012, 34.43% of Rio in 2022), *Vitex agnus-castus* (0% cover of Rio in 2012, 7.583% in 2022) and *Ludwigia peploides* (8.35% cover at Rio in 2012, 17.66% cover in 2022.

To understand plant species richness at the study sites, SRBP researchers compiled species accumulation curves for 2012 (Figure 14a, Bateman et al. 2014), and I constructed the same curves for plant communities at the three resurveyed sites in 2022 (Figure 14b). Since some of the data from this initial survey have been lost, instead of reconstructing the original curves I generated a modified version of the figure from Bateman et al. (2014) for the three sites in this study (Figure 14b). The 2012 data showed similar species richness among the three reaches, with slightly higher richness at the Price site. The species accumulation curves for the three sites in 2022 showed the highest species richness at the Tonto site and the lowest at the Price site, suggesting species (both native and non-native) have been more readily introduced and established at the restored and managed sites, both of which also experience more human activity.

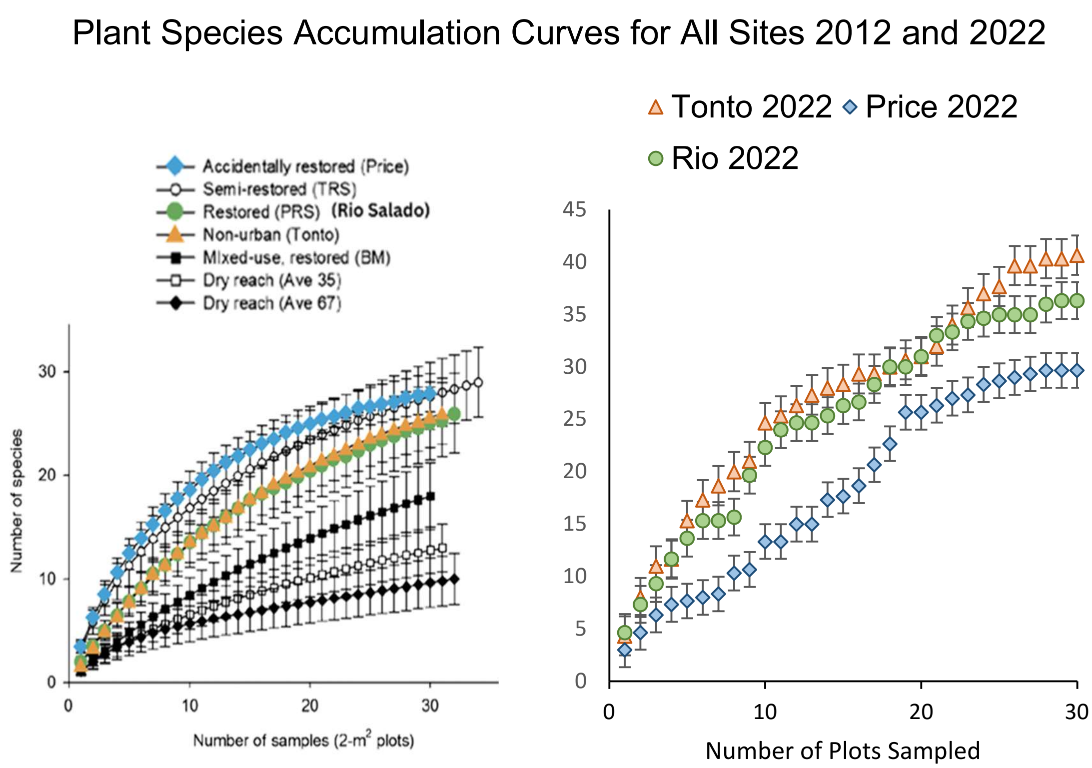

Figure 14: Species Accumulation Curves for all sites. Note the black and white data points on the 2012 (left) chart are SRBP sites that have not been resurveyed (Bateman et al. 2014).

Curves for both Tonto and Rio Salado also did not completely plateau, suggesting actual species richness is likely even higher than I detected in these reaches of the river. Species richness was lowest at Price in 2022 but was not significantly lower than in 2012, rather remained at slightly below an annual mean of 30 species. This stability suggests either less frequent dispersal of plants into the area or ecological limits, such as soil characteristics, on the establishment of some new populations.

Pairing plant species richness curves with the assessments of abundance suggested that richness and abundance are not necessarily coupled in urban Salt River ecosystems. Tonto saw little change in abundance, yet its species richness has increased by approximately 50%. Price, on the other hand, showed an increase in abundance while species richness did not change. Rio Salado, on the other hand, saw increases in both its plant abundance and diversity, potentially stemming from regular plantings, accidental introductions, and water availability.

To examine these contrasting trends, I used the Shannon-Wiener Diversity Index (SDI), which combines species richness and abundance of each species with overall abundance of the community (Shannon 1948, Clarke and Warwick, 2001, Magurran 2004, Ortiz-Burgos 2015). The SDI presents a nondimensional value usually ranging from 1.5 (low diversity) to 3.5 (high

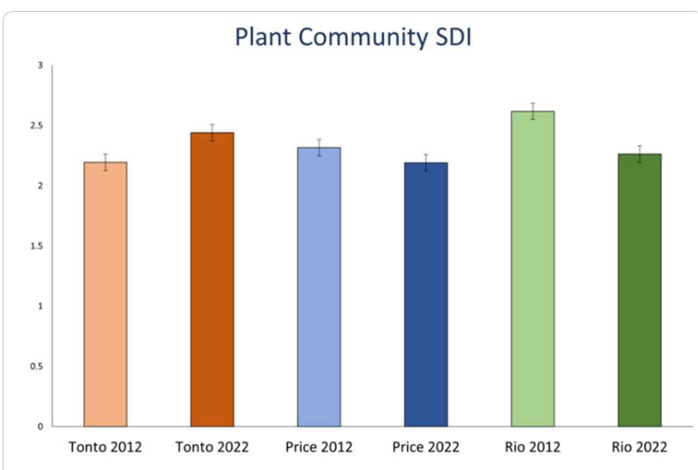

Figure 15: Shannon Diversity Index for each site, 2012 and 2022. Error bars are standard error.

diversity) to provide an estimate of the diversity and evenness of populations. Figure 15 shows the SDI for all sites during both 2012 and 2022. The SDI at Tonto increased (from 2.193 to 2.44), while the other two sites both decreased: Price from 2.315 to 2.19 and Rio from 2.617 to 2.262. The decrease in SDI at Rio was the largest change, indicating that even though plant abundance and species richness increased, the community is more dominated by a few prolific species: *Arundo donax, Ludwigia peploides,* and *Salix gooddingii.*

3.2 SITE-SPECIFIC RESULTS

3.2.1 TONTO

Tonto supported the greatest number of reptile species and was home to several species not found in urban sites. Tonto was the only reach where Desert Spiny Lizards (*Sceloropus magister*), Zebra-Tailed Lizards (*Callisaurus draconoides*), and Long-Tailed Brush Lizards (*Urosaurus graciosus*) were observed. Several unique snake species were also observed only at Tonto, including the Western Patch-Nosed Snake (*Salvadora hexalepis*) and Western Threadsnake (*Leptotyphlops humilis*).

Tonto also supported the highest abundance of birds and saw no significant change in abundance from 2014 - 2022. This community was largely composed of birds who prefer riparian habitats but are not exclusively observed there (Fig 16). It included a large population of Cliff Swallows (*Petrochelidon pyrrhonota*), who nest by the hundreds on the muddy cliff near the transect. On the other hand, few urban-dwelling birds, such as Rock Pigeons (*Columbia livia*) were recorded. Sonoran upland birds, the second-largest habitat guild at Tonto, were more abundant at this site than urban sites, finding ample habitat and foraging opportunities along with the increase of upland and xeric plants. Phainopepla (*Phainopepla nitens)* were common at this site but were not found at the urban sites. Phainopepla are known seed dispersers for Mesquite mistletoe (*Phoradendron californicum*; Aukema and Martinez del Rio 2002), which was also more commonly observed at this site than the urban sites.

While plant abundance increased across all study sites, Tonto alone showed little change in plant abundance, and many species of shrub, such as *Baccharis sarothroides* and *Bebbia juncea,* declined in abundance. This decline is

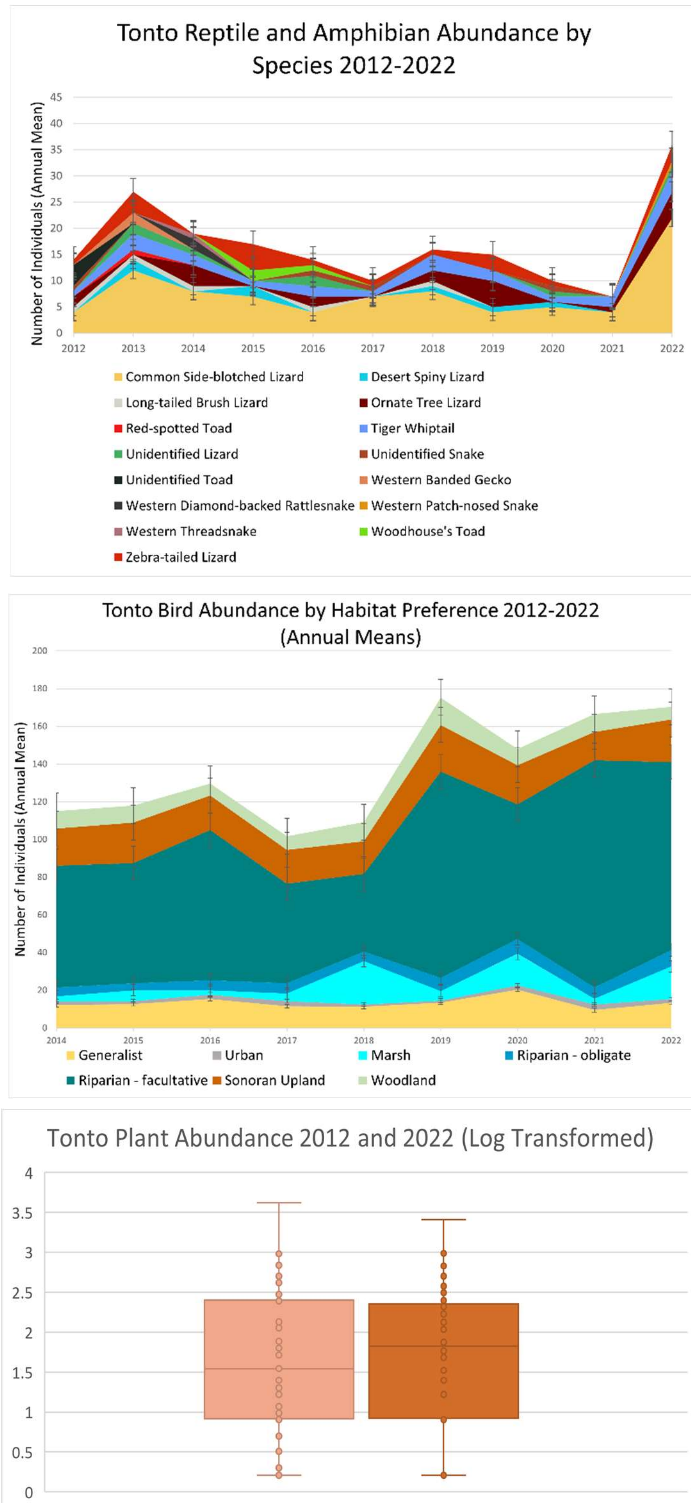

Figure 16: Abundance for all taxa at Tonto: Reptiles by species 2012-2022, Birds by habitat preference 2014-2022, Plants by mean annual cover percentage (log transformed, base 10) 2012 and 2022. Scatter Plot versions of Bird and Herpetofauna Community Composition are included in Appendix C.

likely a result of the combined pulse of the 2017 Cactus Fire with the continued press of wild horses grazing on seedlings. Cacti and thorny plants such as *Prosopis spp.* and *Parkinsonia spp.* were more common than other perennials, perhaps because they are less vulnerable to grazing. Grazing has contributed to shrinking marsh patches and inhibited the recruitment of tall trees such as Cottonwoods and Willows. Marshes and gallery forests are vital habitat for many bird species, including the endangered Southwestern Willow Flycatcher. My findings illustrate a potential link between grazing pressures and threats to wildlife communities, but it is worth noting that bird populations were stable, so some species, such as members of the Sonoran Upland habitat preference guild, may benefit from the simpler and and more open habitat structure.

While plant abundance at Tonto was similar in 2012 and 2022, the plant community had become more species rich by 2022. Part of this was an increase in annuals, which combined made up roughly a third of all plant cover in 2022. The management efforts of US Forest Service have sought to maintain native plant species cover, though prohibited species continue to grow in the area, primarily *Tamarix chinensis* and *Arundo donax*. Culturally important plants declined in abundance, suggesting a disconnect between conservation efforts based on biogeography and efforts focused on plants with cultural ties.

Examining the wetland indicator status of plants at Tonto revealed a shift toward more xeric, upland plant communities. Obligate and facultative wetland plants declined from 6.49% annual mean cover in 2012 to a mere 1.82% annual mean cover while upland plant communities grew in abundance from 7.86% to 12.78%. This shift to drier landscapes is consistent with regional studies on the ongoing multi-decadal drought and continued aridification of the region, which will be accelerated by human-induced climate change (Williams et al. 2020). Plants adapted for survival in xeric conditions are well suited for the drier climactic conditions, including altered and shrinking groundwater reserves.

Examining changes in growth habit at Tonto confirmed how the structure of the ecosystem has shifted. Tall trees such as *Populus fremontii* that provide canopy habitats declined in abundance; while some still tower over the riverbank, I saw few young trees of this group. Shrubs and subshrubs also declined in abundance. On the other hand, graminoids and forbs increased in abundance, including many grasses—such as *Bromus rubens, Schismus arabicus,* and *Bouteloua aristidoides*—and wildflowers, including *Castilleja exserta, Erodium cicutarium,* and *Eschscholzia californica.* This may be a result of grazing and trampling pressure that reduces recruitment of some plants while enhancing dispersal of others. This altered community structure may also be related to post-wildfire succession, but further research would be needed to explore how these factors affect community composition.

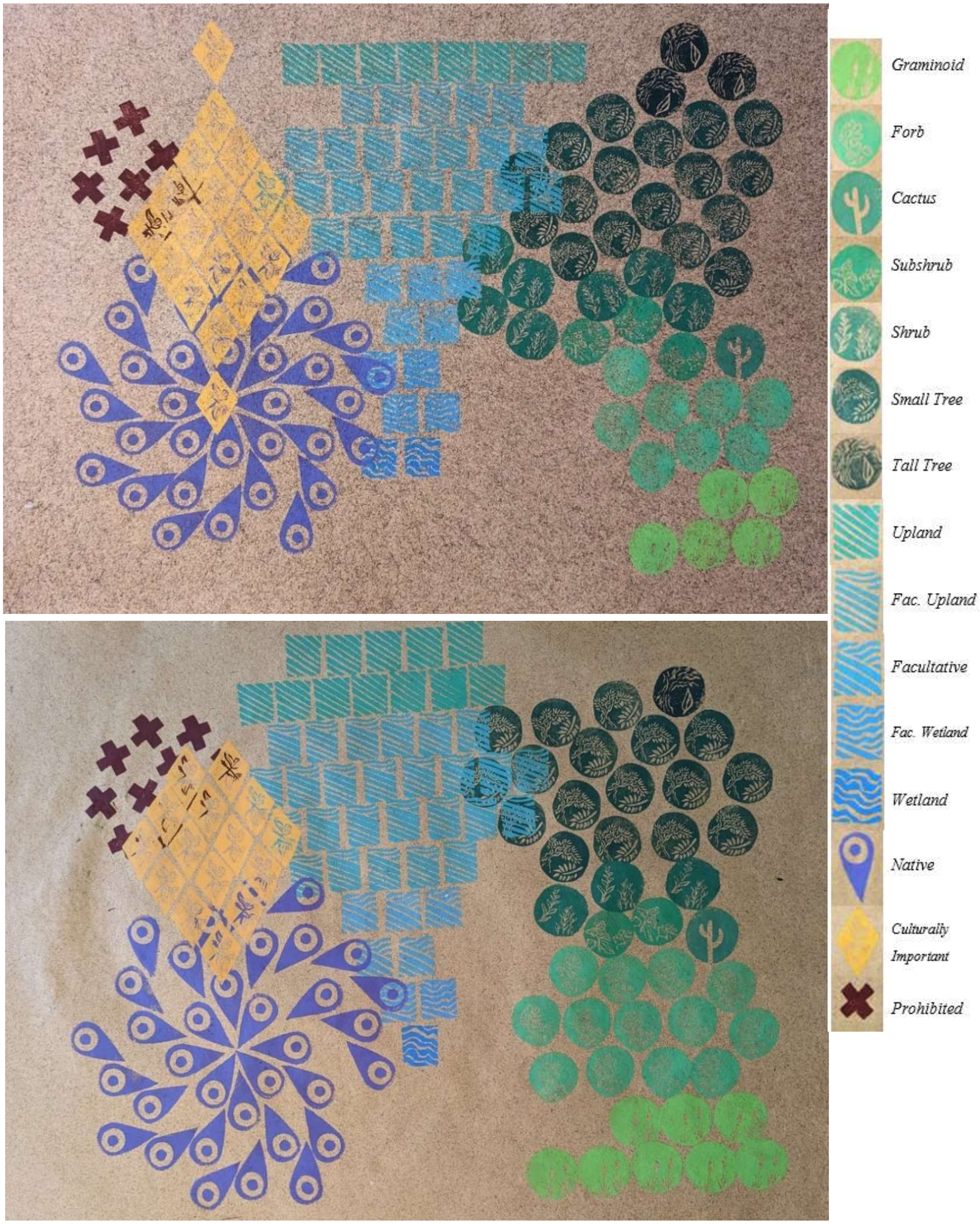

Figure 17: Plant community composition of Tonto, 2012 and 2022, hand printed relief stamps on Typha *and* Arundo *paper. Each stamp represents one percent annual mean cover of a group of plants. Categories of plants move from socially determined on the left to biophysically determined on the right (Prohibited, culturally important, native, wetland indicator status, then growth form). Note that Tonto is the only site that decreased in abundance of Culturally Important species. It also shifted from wetland to upland species and from taller trees and shrubs towards forbs and graminoids potentially responding to pressures of herbivory and aridification.*

3.2.2 PRICE

Nestled below the intersection of a major highway interchange, the Price wetland is a wild pocket of habitat within an urbanized landscape. Its dense stands of Arundo and Tamarix were the hardest terrain to navigate of all the research sites. Over the years, people have repeatedly built homesteads in this reach, but law enforcement and floods regularly push them out. This is the only form of management conducted at this reach, so in some ways the ecosystem's non-human biotic community reflects a hands-off management for urban wetlands.

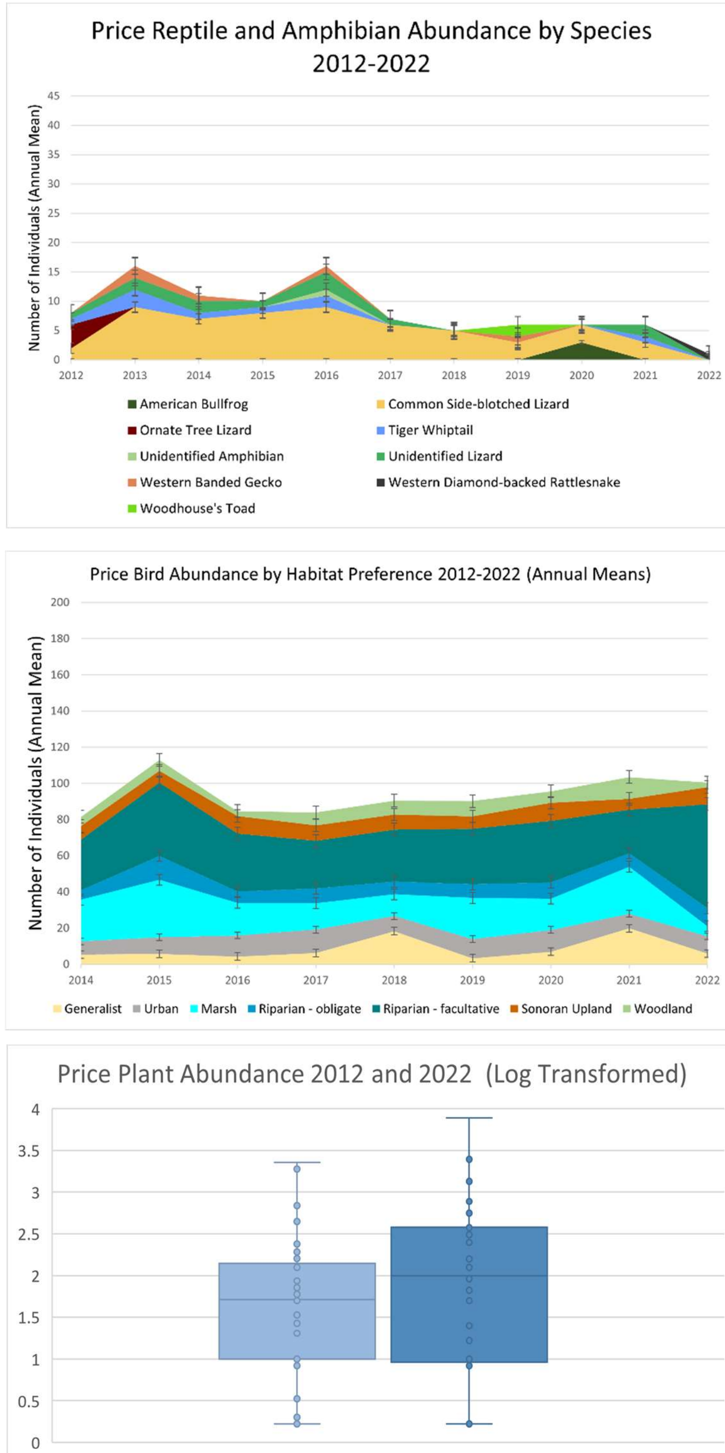

Figure 18: Abundance for all taxa at Price: Reptiles by species 2012-2022, Birds by habitat preference 2014-2022, Plants by mean annual cover percentage (log transformed, base 10) 2012 and 2022. Scatter Plot versions of Bird and Herpetofauna Community Composition are included in Appendix C.

Price supported the fewest species of reptiles and amphibians, and the lowest abundance (Fig 18a). Even common species such as *Uta stansburiana* have become less abundant since 2012. One introduced species, the American Bullfrog (*Lithobates catesbeiana*) was observed at Price, though only in 2020.

Bird abundance at Price did not change significantly between 2014 and 2022. All habitat preference groups were observed at the site, but birds favoring riparian forests and marshes were more abundant than upland or woodland species (Fig 18b). The site's dense marsh and riparian vegetation provide foraging and shelter, especially during the summer's extreme heat when shade and water can be vital to survival. In particular, numerous Black-Crowned Night Herons (*Nycticorax nyticorax*) were observed, as well as large flocks of migratory waterfowl in winter surveys.

Plant abundance at Price increased between 2012 and 2022, primarily due to growing populations of *Tamarix (spp.* 22.75% to 100.333% total annual cover), *Arundo donax* (0.5% to 9.25%), *Typha spp.* (1.5% to 7.75%), and *Pluchea spp.* (1.883% to 8.467%). All four of these plants grow in quickly expanding monotypic stands and are frequently targets of land managers concerned about the spread of invasive (*Tamarix spp.* and *Arundo donax*) or nuisance (*Typha spp.*) species because they are thought to cause a reduction in biodiversity. Species prohibited for these reasons by the Salt River Pima-Maricopa Indian Community are now more than twice as abundant as they were in 2012. However, despite the growth in abundance of exotic species, overall plant species richness was not lower in 2022 than it was in 2012 (Fig 18c). This lack of change could be a result of the regular (re)introduction of species from the urban landscape via storm drains and waterfowl. Native and non-native species may easily disperse into this site via

Figure 19: Ammannia coccinea *(left) and* Ludwigia erecta *(right), both with* Pluchea odorata *in the background.*

human mechanisms, dispersal by migratory birds, and environmental factors such as flooding . Two examples are *Ammannia coccinea* and *Ludwigia erecta* (Fig 19). *Ammannia coccinea* is a regionally native obligate wetland species, found upstream on the Salt and Verde Rivers, but is not typically found in low-lying arid desert landscapes. It has been collected on rare occasions in the Phoenix area only in the bed of the Salt River downstream of the Price St. storm drain. *Ludwigia erecta,* another obligate wetland plant, is common in warm temperate regions across Central America and Africa. It is extremely rare in the United States and does not have an English common name, but in Spanish it is called Yerba de Jicotea, which roughly translates to Turtle Grass. It has only been collected in Arizona in the area immediately downstream of the Price drain, first in 2006, then 2010, and now 2022. The next closest collections are more than 1000 km away near Culiacan, Sinaloa in Mexico and Galveston, Texas in the USA (SEINet 2023). *Ludwigia erecta* and *Ammannia coccinea* both have established at this site, but their need for particular conditions such as waterlogged soils likely make dispersal of both species further throughout the region difficult.

While species from all over the world continue to arrive and establish in the Price site, native species also continue to thrive. Native and Culturally Important species both increased in abundance at Price. This includes the expanding stands of Arrow weed (*Pluchea sericea*) mentioned above. Perennial plants such as *Pluchea spp.* seem to do especially well in the accidental wetland, as perennial plant cover increased from 32.9% (annual mean) to 60.1%, while the abundance of annuals in 2022 was roughly half that of 2012.

Facultative plant species were more abundant in 2012 than either obligate wetland or obligate upland species. This reflects the adaptable nature of several of the most abundant plants at the site, including *Arundo donax, Salix spp., Tamarix spp., Pluchea spp.,* and *Prosopis spp.* While these plants are all characteristic of riparian areas, they can thrive in both inundated and dry conditions. This makes them well suited to the variability of the urban Salt River, which can vary between sudden floods that fill the whole river bed in monsoon season to months with only shallow, muddy water in the central channel.

Plant community structure at Price was similarly characterized by the growth habits of the most abundant plants. No category of growth habit at Price was significantly lower in 2022 than in 2012, and small trees grew the most in mean annual cover. Small trees covered only 11.6% of the Price site in 2012 but 29.2% in 2022. Both *Tamarix spp.* And *Prosopis spp.* fall into this category and were more abundant than in 2012.

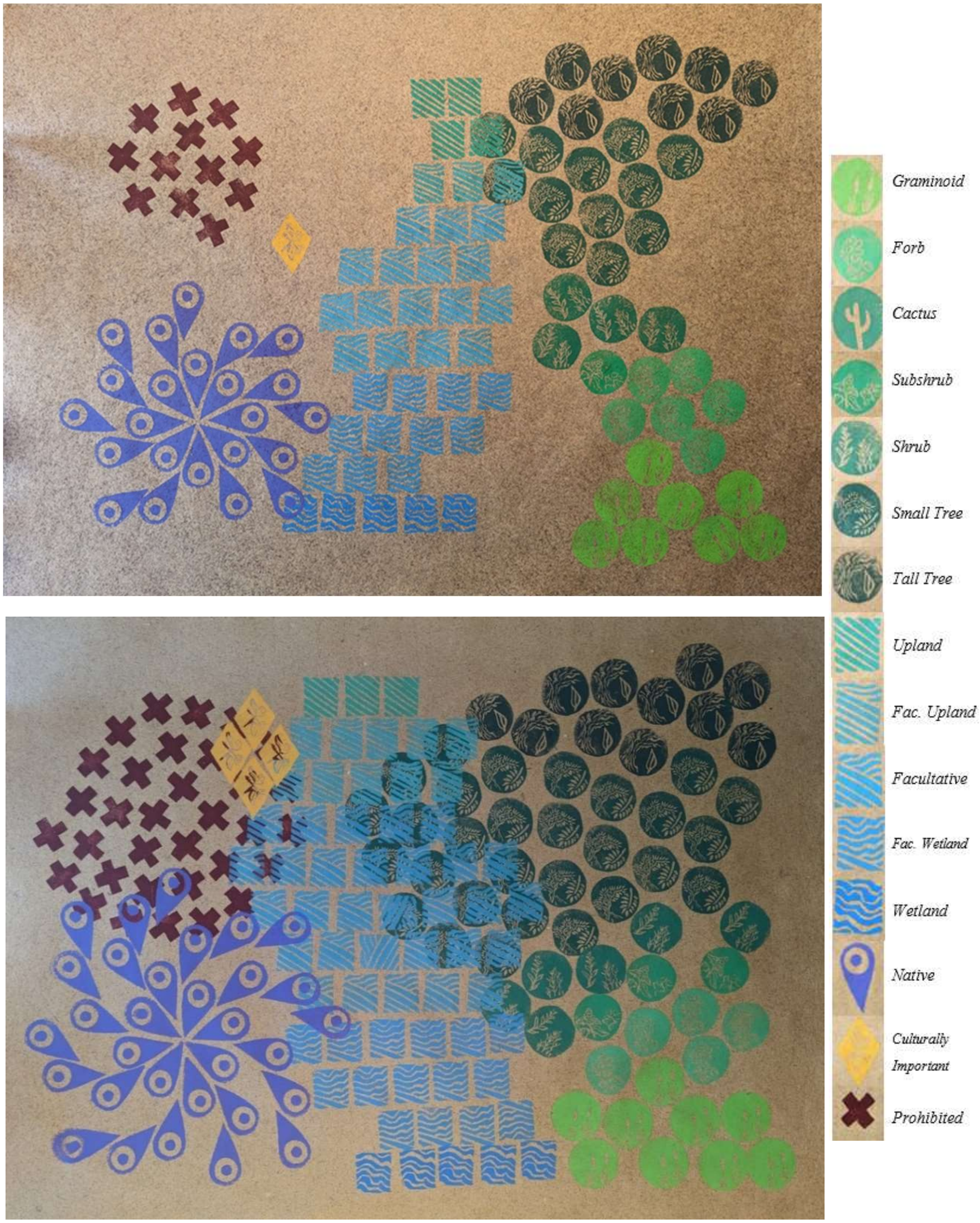

Figure 20: Plant community composition of Price, 2012 and 2022, hand printed relief stamps on Typha *and* Arundo *paper. Each stamp represents one percent annual mean cover of a group of plants. Categories of plants move from socially determined on the left to biophysically determined on the right (Prohibited, culturally important, native, wetland indicator status, then growth form). Notice the swelling abundance of small trees and facultative plants, including* Tamarix *and* Arundo. *Also note the increase in native and culturally important species without active planting.*

3.2.3 RIO SALADO (RIO)

In the midst of the concrete and gravel of Central Phoenix, Rio Salado provides vital habitat for wildlife that have adapted to life in fragmented urban habitat patches. The dense forests on the slope to the riverbed support a large population of Ornate Tree Lizards (*Urosaurus ornatus*), which were much less common at the other urban site (Fig 21a). The only snake observed was a Checkered garter snake (*Thamnophis marcianus*). This common southwestern snake species may reproduce by parthenogenesis (Reynolds et al. 2012), potentially improving its chance of persisting in

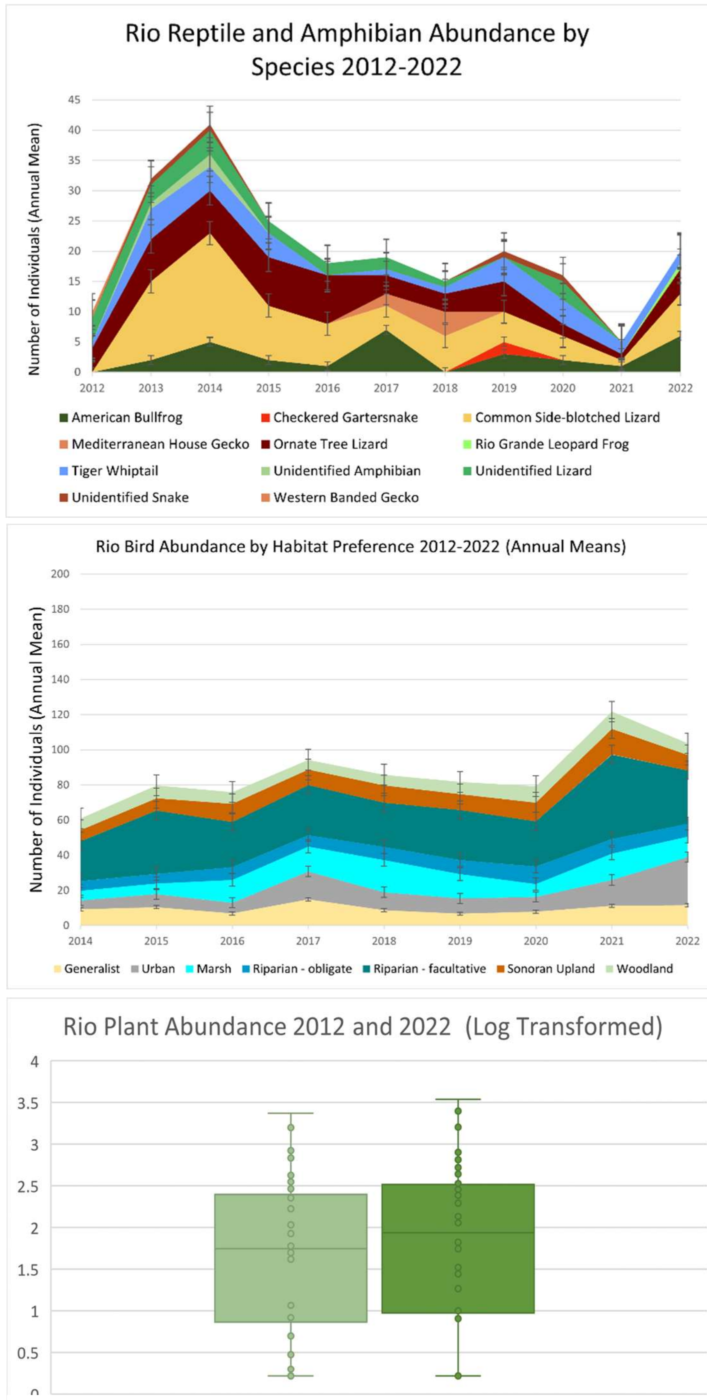

Figure 21: Abundance for all taxa at Rio Salado: Reptiles by species 2012-2022, Birds by habitat preference 2014-2022, Plants by mean annual cover percentage (log transformed, base 10) 2012 and 2022. catter Plot versions of Bird and Herpetofauna Community Composition are included in Appendix C.

fragmented habitats that make breeding difficult. American bullfrogs (*L. catesbeiana*) were observed in eight of ten years at Rio Salado; these voracious (and edible) amphibians are growing in population worldwide (Both et al. 2011, Chang et al. 2022) while globally most amphibians are declining in abundance (Gardner 2001, Vredenburg and Wake 2007). Introduced Mediterranean house geckos (*Hemidactylis turcicus*) were also observed, as well as a single Rio Grande leopard frog (*Lithobates berlandieri*) that was observed in 2022. This is consistent with its documented expansion through the area since its accidental introduction near Yuma in the 1960s (Miera and Sredl 2000). While reptiles are declining in abundance and richness at both urban sites, Rio Salado has recently supported more than double the reptile population compared to the Price site, suggesting that ecosystem restoration and management are important for urban herpetofauna communities.

Rio Salado was the only site that showed a significant increase in bird abundance by more than 40% over the study period, from an annual mean of 68.5 birds in 2014 to 107.333 in 2022 ($p=0.0174$). Urban-adapted birds such as Great-Tailed Grackles (*Quiscalus mexicanus*) and Eurasian Collared-Doves (*Streoptopelia decato*) make up a large portion of this increase, but all habitat preference groups were consistently present at the site. Osprey (*Pandion haliatus*) were observed hunting and nesting in the area. This vibrant bird community illustrates one of the links between this system's social and biophysical elements. The City of Phoenix and Audubon Southwest manage the area for bird habitat, apparently successfully. These birds have become charismatic representatives of the ecosystem for urban dwellers who are not otherwise frequently in contact with wildlife.

The plant community at Rio Salado increased in both species richness (Figure 14) and abundance (Figure 20) from 2012 to 2022, but the Shannon Diversity Index decreased (Figure 15). This contradiction is attributable to several opportunistic species that greatly increased in abundance over the decade. Many of these species are native to other biogeographic regions and have been introduced through human activity, such as *Cenchrus ciliaris* (2.4% cover in 2012, 4.9% in 2022), *Arundo donax* (0% cover in 2012, 5.3% in 2022) *Vitex agnus-castus* (0% cover in 2012, 7.6% in 2022) and *Ludwigia peploides* (8.4% cover in 2012, 26% in 2022). *Ludwigia peploides,* which carpets the surface of the water in summertime with its broad green leaves and small yellow flowers, belongs to the same genus as *Ludwigia erecta*, the rare plant collected at Price. However, the regular planting, irrigation, and care of native plants in this restoration area has also led to the substantial growth in abundance of some regionally native plants, such as *Ambrosia ambrosioides* (3.5% total cover in 2012 and 11.2% in 2022), *Populus fremontii* (15.8% total cover in 2012, 21.4% in 2022) *Prosopis velutina* (23.4% total cover in 2012, 48.5% in 2022), and *Salix gooddingii* (8.7% total cover in 2012, 43.1% in 2022).

Figure 22: Ludwigia peploides *(Floating Water Primrose) carpets the surface of the water in summertime with its broad green leaves and small yellow flowers, belongs to the same genus as* Ludwigia erecta*, the rare plant collected at Price (Carnahan, SEINet 2023).*

Figure 23 illustrates this substantial growth of both native and introduced plants. Native species—usually desired by restoration practitioners— made up >10% more of the site's mean annual cover in 2022 than in 2012. Yet culturally important species did not change in abundance over the decade, indicating that the native species aided by these restoration efforts are not always the species most important to local indigenous ecological practices. Just as native plants grew in abundance, prohibited plants also increased, covering 10% more of the site in 2022 than in 2012, despite frequent removal efforts. These results suggest that while restoration efforts like Rio Salado (which has cost more than $110 million to build and manage) cannot fully prevent the spread of introduced species, they can help support the continued growth of some native species within a cosmopolitan ecosystem.

The abundance of wetland species (both obligate and facultative) increased slightly at the Rio Salado site relative to upland species. Land managers at Rio Salado pump groundwater to maintain a low-flow channel in the restoration area, which helps support these perennial wetland communities. In addition, as the Phoenix downtown area continues to develop and become more impermeable, the volume of water discharged from the 33 storm drain outfalls will likely increase. This perennial water availability is crucial for plants and animals living through dual crises of a regional mega-drought (Murphy and Ellis 2017) and an intensifying urban heat island (Connors et al. 2013).

Of all growth habits, tall and small trees increased the most in cover over the decade. This also may be a result of the dual pressures of species introductions and management for restoration goals. Some tree species, such as *Vitex agnus-castus* (0% cover in 2012, 7.6% in 2022), *Parkinsonia aculeata* (0.02% total cover 2012, 6.5% in

2022), and *Washingtonia robusta* (0% total cover in 2012, 5.3% in 2022) are routinely targeted for removal by the City of Phoenix but continue to recolonize the site. On the other hand, city land managers regularly plant several species in the area, and even in some cases install irrigation systems to support their growth. *Salix gooddingii* (8.67% total cover in 2012, 43.1% in 2022) and *Populus fremontii* (15.8% total cover in 2012, 21.4% in 2022) both benefit from this management.

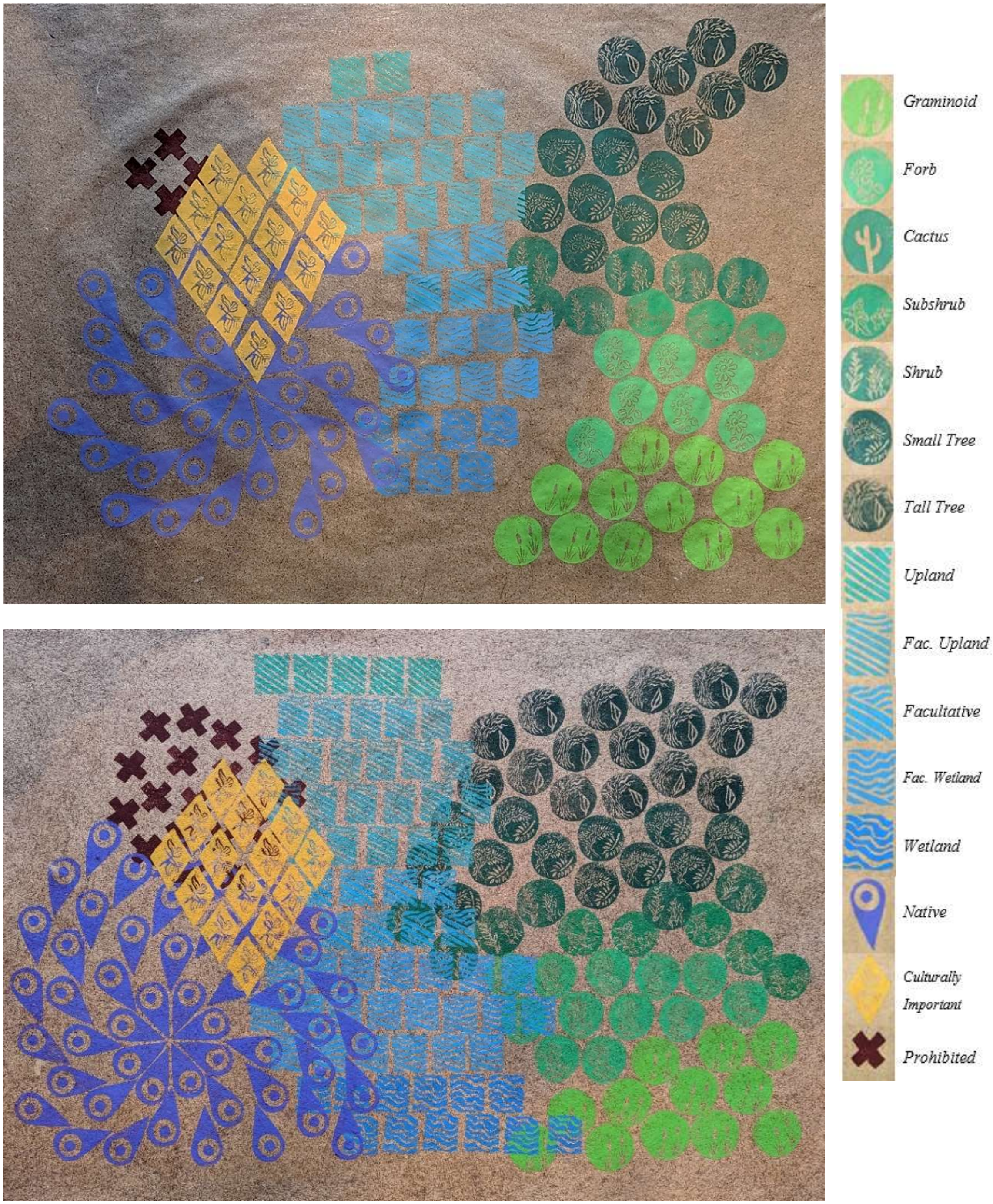

Figure 23: Plant community composition of Rio Salado, 2012 and 2022, hand printed relief stamps on Schoenoplectus *and* Typha *paper. Each stamp represents one percent annual mean cover of a group of plants. Categories of plants move from socially determined on the left to biophysically determined on the right (Prohibited, culturally important, native, wetland indicator status, then growth form). Note that in Rio Salado, every single group increased in abundance. Native species like Willows* (Salix), *Arrowweed* (Pluchea), *and Mesquite* (Prosopis)*, increased alongside introduced plants like Chaste Tree* (Vitex), *Water Primrose* (Ludwigia peploides), *and* Arundo. *Restoration efforts have not prevented introductions but have promoted a balanced habitat structure, which is an important factor for habitat provision and ecosystem services.*

3.3 PAPERMAKING

Both marshes and riparian forests are important habitat patches in the urban Salt River, and are often characterized by a few abundant plant species; Table 1 shows which marsh and riparian species were most abundant in the study sites in 2012 and 2022: *Arundo, Prosopis, Salix, Schoenoplectus, Tamarix,* and *Typha*. These species are all key for ecosystem functions such as habitat provision and nutrient cycling and have long been used by humans for food, construction, and crafting material. However, they are often targeted for removal in invasive species management plans. Since these species are foundations of ecosystem services and functions, and readily removed by land managers at some of the study sites, I chose them to make paper to form the backdrop for data visualization. Marsh graminoids were easier to process in a limited amount of time, so I used the three marsh species for the artworks shown in this paper, but I also experimented with the use of *Tamarix* fibers since Saltcedar is so frequently removed in regional restoration efforts. After I completed surveys in October 2022, I worked with land managers—City of Phoenix and City of Tempe—to harvest some of these abundant marsh and riparian species alongside ongoing ecosystem management efforts. I worked with City of Phoenix to harvest *Arundo donax, Schoenoplectus californicus,* and *Typha latifolia* from the Rio Salado Restoration area, where they have been frequently removed from stormwater infrastructure by park staff and volunteers since restoration efforts began in the late 1990's.

Table 1: The most abundant species of emergent marsh vegetation and trees at each study site.

	2012	2022
Tonto	*Typha latifolia, Prosopis velutina*	*Arundo donax, Prosopis velutina*
Price	*Typha latifolia, Tamarix chinensis*	*Arundo donax, Tamarix chinensis*
Rio	*Prosopis velutina, Schoenoplectus sp.*	*Typha latifolia, Salix goodinggii*

In 2022, City of Tempe removed *Tamarix chinensis* from several reaches of the Salt River bed as part of a public safety initiative, and provided me with biomass for papermaking. Below I explain the results of making paper with these four species. To see more images of each paper, refer to Site Specific Results (Section 3.2) or Appendix A.

Exploring the potential of these plant species for papermaking not only investigated an avenue for collaboration between land managers and artists, but also helped me understand and relate to common plants of the Salt River more directly. I learned about their structure, the texture of their fibers, and the different ways their tissues change as they are dried or soaked. While ecological field work involves a direct, tactile relationship with the landscape, many modes of ecological analysis do not. By integrating papermaking and printmaking into my analysis, I reintroduced an embodied and personal relationship with these plants, in which they became tangible collaborators in the visualizations of their ecosystems.

3.3.1 Arundo donax – Giant Reed (Tonto 2022, Price 2022)

Arundo donax, a massive grass species that can grow up to over six meters, has spread mostly clonally alongside humanity for millennia, from its origin in the Middle

East to near global distribution (Hardion et al. 2014). Humans have used *Arundo* for everything from medicine to construction, and even paper. *Arundo* increased greatly in abundance at all three study sites and was the most abundant marsh species at both Tonto and Price in 2022. At Rio Salado, it grows inside stormwater outfalls, slowing and diverting the flow of water by essentially creating a garbage dam. City of Phoenix Park Rangers, a small group from a local scout troop, and I cleared out one of these drains, which is the source of *Arundo* fiber used in this project.

I made two kinds of pulp with *Arundo,* one from its long bladelike leaves, and one from its hard culms. Both were successful but required different procedures and created different results. The leaves, which had longer, stringier, tougher fibers, were cooked for roughly eight hours and beaten for five hours. I had to cook the culms—which had shorter and harder fibers—for over ten hours, but they took less than two hours to beat. The long leaf fibers, resembling kozo and other traditional Japanese paper fibers, resulted in a strong but variable texture and color paper. The culms, on the other hand, created very smooth, pale colored sheets that were more similar to commercially-made paper. In order to retain the character of the leaf fiber but have a more usable paper surface, I combined the pulps to make a mixture of 50% of each for the final artworks.

3.3.2 Schoenoplectus californicus – California Bullrush (Rio 2012)

Schoenoplectus spp., bulrushes, are a distinctive wetland sedge that humans have used for medicine, food, crafts, and construction worldwide (Watson et al. 2020). *Schoenoplectus spp*. was planted in Rio Salado in the early 2000's as part of the original restoration efforts, and they were the most numerous wetland sedge in 2012. In 2022, *Typha* and *Arundo* had higher abundance, but multiple *Schoenoplectus* species were found. Since they are not actively removed by land managers, I asked for permission to harvest some plants during the winter (late January 2023) after the plants had senesced. I cut and retted the spongy stalks, which were very light for their size and easy to cut. After six weeks of field retting, I cooked them in a soda ash solution. The spongy, porous nature of its tissues soaked up the solution and quickly softened the fibers; I only needed to cook them for three hours, but their porous fibers soak up the caustic solution, so it was more difficult to thoroughly rinse the *Schoenoplectus* fibers than other plants. After less than an hour in the Hollander beater, the fibers were short, soft, and evenly suspended. The sheets were delicate, often ripping when couched and retained a lot of moisture, again due to the spongy fibers. The resulting sheets were a dark, reddish brown (See Figure 22) and took longer to dry than *Arundo* or *Typha* fibers.

3.3.3 Typha latifolia – Broadleaf Cattail (Tonto 2012, Price 2012, Rio 2022)

Typha spp., cattail, is one of the most cosmopolitan and recognized wetland plants. It has long been used for crafting and food (Kimmerer 2013), and its contributions to wetland ecosystem services have been well documented (Vroom et al. 2018, Bansal et al. 2019). However, many land managers are concerned with Cattail's rapid growth into monotypic stands, which can have negative effects on wetland ecosystems (Bansal et al. 2019) and disrupt infrastructure in constructed or managed wetlands (City of Phoenix, personal correspondence 2022, Gila River Indian Community, personal correspondence 2023). I worked with City of Phoenix as they cleared stormwater infrastructure overgrown with *Typha latifolia*, and I harvested seed heads from these cleared plants to use for paper fibers.

I stripped the corndog-like seed heads from their stalks while submerged to prevent the seeds from blowing away. Once this step was complete, processing the seed heads for pulp was fairly quick since the fibers were already soft and short. Cooking them just 90 minutes was enough to separate the seeds from the downy tissues, but the seeds also released a reddish pigment that carried through into the final paper. I beat the fibers less than an hour, as I only needed to have them evenly distributed through the pulp. While easy to process, these fibers were less easy to pull into consistent sheets of paper; the fibers were so short that they often became uneven and clumped. The resulting paper is delicate, soft, and similar to thin felt.

3.3.4 Tamarix chinensis – Saltcedar/Tamarisk

One of the most undesirable introduced species in the American Southwest, *Tamarix spp.* (or Saltcedar) thrives in locations and conditions that are too harsh for many other plants, including the salty and scorching bottomlands of Death Valley and the dry, sunbaked reaches of the Salt River bed. Its ability to thrive in these harsh conditions makes it valuable habitat for some wildlife (Sogge et al. 2008), but its benefits are inconsistent across animal taxa (Bateman et al. 2013). Its high transpiration rate, high combustibility, and habit of growing in monotypic stands have all contributed to land managers' desire to remove or eradicate *Tamarix spp.* from along Western rivers. The City of Tempe frequently removes Saltcedar, and managers were able to provide biomass for papermaking.

Tamarix fibers did not work well for paper pulp. The fibers released a salty and oily secretion as they broke down (both mechanically and in the caustic solution) that made the branches hard to work with, chafing and staining my hands, even when wearing gloves. I soaked the fibers for more than four days and cooked the fibers repeatedly, for a total of 18 hours. This produced a brilliant red solution that stained tools and surfaces so could potentially be used as a dye. Yet the fibers remained tough and splintery. Some cambium fibers between the bark and wood seemed promising for bast, but there was not enough in the available biomass to make pulp. The rest of the fibers remained splintery despite maceration by the beater for two hours, after which they did not change in consistency with further beating. They did not have the length, strength, or adhesive properties needed to pull thin, strong, or consistent sheets of paper. However, with additional adhesives, *Tamarix* fibers could potentially be used as wood for fiberboard.

4. CONCLUSION

Urbanization and climate change exert increasing pressures on arid wetlands. Along the Salt River, urban pressures have facilitated increased plant abundance, which in turn created complex habitat for increasing bird populations. However, reptile and amphibian populations declined, illustrating the vulnerability of herpetofauna to urbanization and climate change. In coupled social-ecological systems such as urban wetlands, human management is critical for ecosystem stability, and long-term monitoring is necessary to understand results of different management modes. All three study sites show outcomes of different modes of urban wetland management: remnant wetlands as recreational areas (Tonto), prohibited access to accidental wetlands (Price), and the restoration and management of degraded wetlands (Rio Salado).

Plant communities at Tonto shifted towards more upland and smaller plants, with increases in grasses, forbs, and thorny shrubs. Native plant species increased in abundance, but culturally significant plants for local Indigenous groups decreased in abundance, suggesting a disconnect between conservation efforts based on biogeography and efforts focused on plants with cultural ties. Habitat structure became less complex as trees and marsh patches thinned, likely because of combined pressures of drought, controlled hydrology, and grazing by horse herds. Despite thinning marshes and gallery forests, the reach is home to stable reptile and bird populations, including species not detected in urban areas. This suggests that some groups of birds and herpetofauna may benefit from more open habitat structure, and land managers should consider tradeoffs between species groups for conservation.

Price wetland plant communities increased in percent cover, mostly due to increases in *Tamarix spp.* and *Arundo donax*, but did not increase in species richness. Native, culturally important, and regionally rare plants are also growing in abundance. The bird populations were stable, showing that even with minimal management, urban wetland plant communities may continue to grow in abundance, providing habitat for stable bird communities and rare and culturally important plants. However, reptiles and amphibians became less abundant, suggesting urban pressures such as roads, feral cats, and the urban heat island effect threaten the survival of herpetofauna.

Restoration and management at Rio Salado fostered growth of native plant species but did not prevent the introduction and growth of cosmopolitan and prohibited plants. This mosaic of regional natives and globally distributed plants creates habitat used by a similarly cosmopolitan population of birds and herpetofauna. Reptiles and amphibian populations were larger at Rio Salado than the other urban site, but still declined, demonstrating the vulnerability of herpetofauna to urbanization even in managed restoration areas. Bird populations grew, indicating successful restoration efforts aimed at supporting complex bird habitat. Future restoration efforts should consider the costs and tradeoffs of introduced species removal as well as explore new methods to support habitat for reptiles and amphibians in addition to bird communities.

By visualizing changes in community composition through relief prints on paper made by hand from plant species from each site, I presented the findings from this study in a form that explores these data through a creative and embodied way of knowing. I investigated the viability of papermaking with four common Salt River plants—*Arundo donax, Schoenoplectus californicus, Tamarix chinensis* and *Typha latifolia*—to explore possibilities for aligning arts practices with management efforts. *Arundo donax* created the strongest paper and is increasingly common in the urban Salt River, suggesting an avenue to align management efforts with local arts communities. In addition to exploring the plants' potential as materials, creating artworks expands audiences for this research and the medium allows plants to be seen and considered by their human neighbors in a new way. This alternate mode of engagement can complement ecological management and research to diversify disciplines and participants engaged with understanding and living alongside urban wetlands.

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APPENDIX A

PAPERMAKING PROCEDURES IN DETAIL

A.1: Arundo donax

I collected *Arundo donax* in December 2022 when stands are mostly in senescence. I collected these in collaboration with the City of Phoenix, Xavier High School Students, and a Boy Scout troop while working with them on a community cleanup of litter and vegetation in stormwater outfalls. I collected about 20 *Arundo* stalks about 3.5 m in height. These tissues were already dormant so had begun to dry out, and I field retted them for another two months. I then separated the culms from leaves and began processing one half kilogram of each for herbaceous and petiole bast, respectively.

I trimmed leaves to <4 cm sections and soaked them overnight. Then I cooked them with 10 liters of water and 100 g of soda ash. I cooked them with 75 g of soda ash for two hours at a pH of 10, then added the remaining 25 g to raise the pH to 11 for another hour and a half. At this stage the fibers were still tough. I rinsed the fibers, soaked them for 48 hours, then cooked them again, this time with 15 L of water and 200 g of soda ash, for four and a half hours of a rolling boil at pH 11. I left the fibers to sit in the caustic solution overnight, then rinsed the fibers. Once rinsed, I beat the fibers in a Hollander beater, but they were still long, stringy, and tough so quickly clogged the beater. I unclogged and cleaned it, and trimmed the fibers again, this time to roughly one centimeter in length, as I added them back to the beater. I circulated them with no weight on the beater (basically allowing fibers to circulate evenly while being gently massaged) for an hour and a half, then incrementally increased the weight to the heaviest setting, where the beater drum is grazing the bedplate with each rotation. I macerated the fibers on this heavy setting for three hours. During this process, the fibers foamed up the bath, so I had to periodically skim foam from its surface. I tested the fibers' suspension and once they were evenly suspended, I raised the beater to its medium setting for half an hour, the light setting for half an hour, and then no weight at all for fifteen minutes. The resulting pulp was thin and clumped but was also very strong. The resulting sheets had varied coloration and texture but were quite durable.

I trimmed the culms to <4 cm and soaked them overnight. I then steamed the culms for two hours, allowing the layers of tissue to separate. I stripped the slick, lignin-rich outer layer off of the softer cellulose-rich inner layers. I cooked these inner tissues with 10 L of water and 150 g of soda ash, maintaining a pH of 11 for three and a half hours. I rinsed the fibers, soaked them for another hour and a half, and then cooked them again, this time continuously adding soda ash to maintain a pH of 11 for seven hours. After this, I rinsed the fibers and added them to the beater. These fibers were short and soft, so required less time than the petiole bast from *Arundo.* I beat them for ten minutes with no weight, then moved it up to the heaviest setting, at which I macerated them for one hour, after which they were suspended evenly and workable. I backed the pressure down incrementally over ten minutes and proceeded to pull sheets. These sheets were a pale cream color with a consistent, smooth texture and much easier to pull an even sheet.

I found the culms much easier to work with and the resulting sheets were much easier to print on. However, the petiole bast sheets were much stronger and displayed the plant fibers much more clearly. I enjoyed the workability of the culms and the direct, more personal presence of *Arundo* in the leaf papers, so for the final pieces I included in the Results and Discussion section here, I mixed both pulps together to create smooth sheets that still allowed the plant fibers to be seen.

A.2: Typha latifolia

Common cattails are found on every continent but Antarctica, carried by wind and nourished by any trickle of water available. The City of Phoenix both appreciates the presence of *Typha* for its role in water quality regulation in restored and constructed wetlands, but is also constantly removing cattails from stormwater infrastructure to avoid clogging outflows. I worked with the City of Phoenix to harvest 20 seed pods from an especially overgrown outflow at 7^{th} Ave. I retted these fibers two weeks and then stripped the seeds from the stems while the corn dog-like seed pods were submerged in a bucket of water to avoid causing massive dispersal events. I cooked one half kilogram of these seed pods with 10 L of water and 100 mg of soda ash, maintaining a pH of 11. Since these fibers were already short and soft, I needed less than 90 minutes to prepare them. The fibers released a red-pink pigment that rinsed off of the fibers in a vivid crimson, and the color persists in the *Typha* paper as a pale pink. I added the fibers to the beater and then lowered the bed to maximum pressure. After ninety minutes, the fibers suspended evenly and were sufficiently pliable, so I gradually reduced the pressure and then added them to the vat. These sheets pulled unevenly, often leaving clumps or holes in the pulp distributed across the deckle, and often clung to the deckle when couching. The resulting sheets were delicate and soft, and the fibers could be clearly seen. Overall, *Typha* seed pods are easy to process to prepare for papermaking, and create interesting, soft pink sheets, but these sheets are inconsistent in texture and not very strong. I encourage future attempts to use *Typha* for papermaking to incorporate other parts of the plant as well for structural support.

A.3: Schoenoplectus californicus

Schoenoplectus californicus, one of many bullrush species found in marshes throughout the Southwest, was planted in Rio Salado during restoration (completed in 2006). In 2012, *Schoenooplectus* was the most common marsh plant at the site. *Typha* and *Arundo* were both more abundant than bullrushes in 2022, but *Schoenoplectus* was still a common sight in ponds at Rio Salado. With the City of Phoenix's permission, I harvested a kilogram of dry stems while the plants were in senescence in January of 2023 and retted them six weeks. I cut the stems to half and inch and cooked them with 10 L of water and 150 mg of soda ash. After three hours, the fibers were pliable and soft. I rinsed the cooked fibers and added them to the Hollander beater, beating it for 15 minutes at medium weight and 45 minutes at maximum weight. The bath continually foamed up during this process. After barely an hour of beating total, the fibers were shortened and suspending evenly, so I added them to the vat. The fibers clung well to each other and were easy to couch. The resulting deep brown sheets appeared thick, but were vey spongy and saturated, so after pressing and drying became thin and delicate.

A.4: Tamarix chinensis

Saltcedar is an abundant introduced species that thrives in dry, saline riverbeds. Many land managers in Arizona focus invasive species removal efforts on *Tamarix,* so its tissues were easy to find. In this case, I acquired them from the City of Tempe as they cleared the Salt River bed for "public safety and flood control" (City of Tempe, personal communications 2023). I field retted these cuttings for four weeks, and longer or shorter retting may yield different results. I took 1.5 kg of branches, 2-5 cm in diameter, and soaked them for 48 hours. I then steamed them for an hour, trimmed them to 5 cm lengths, and attempted to separate bark, cambium, and pith. However, the tissues did not separate evenly, so I used a mixture of all three. I cooked them at a pH of 11 for six hours, and then a pH of 12 for four hours. I then rinsed the fibers, soaked them for 48 hours, broke them down further into 2 cm pieces, and cooked them again for six hours at a pH of 11. The fibers were still tough and splintery, so I soaked them in the caustic solution for 48 hours. I tore the tissues apart further and cooked them at a pH of 11 for another ninety minutes, after which they were softer. I rinsed the fibers and added them to the beater slowly, hand stripping and cutting the *Tamarix* into even smaller pieces as I added them. I beat these fibers with no additional pressure for an hour, then raised the pressure gradually. I beat the fibers on the maximum weight for the beater for four hours, periodically checking its fiber length, strength, and suspension. The fibers quickly became short, but they remained brittle and heavy, not binding to each other or suspending in water evenly. The resulting pulp was dense and splintery. I was not able to pull it into even sheets of paper, but the density and malleability of the pulp could be better utilized in other material crafts, such as compression of tissues for use as fiberboard.

APPENDIX B

SPECIES LISTS

B.1: PLANT SPECIES

Binomial	***Common Name***
Abronia angustifolia	*Narrow leaf sand Verbena*

Acacia farnesiana	*Sweet Acacia*
Acacia greggii*	*Catclaw Acacia*
Acacia stenopylla	*Shoestring Acacia*
Amaranthus fimbriatus	*Fringed amaranth*
Ambrosia ambrosioides*	*Canyon bursage*
Ambrosia deltoidea*	*Triangle-leaf bursage*
Ambrosia eriocentra	*Woolly bursage*
Ambrosia monogyra	*Singlewhorl burrobush*
Ambrosia salsola	*Cheesebush*
Ammannia coccinea	*Scarlet toothcup*
Amsinckia tessellata	*Fiddleneck*
Amsinckia menziesii var. intermedia	*Fiddleneck*
Aristida purpurea	*Purple Three Awn*
Arundo donax	*Giant Reed*
Atriplex sp.	*Saltbush*
Atriplex canescens*	*Fourwing Saltbush*
Atriplex lentiformis	*Big Saltbush/lens scale/quail bush*
Atriplex polycarpa	*Cattle Saltbush*
Baccharis salicifolia	*Seepwillow*
Baccharis sarothroides	*Desert Broom*
Bebbia juncea	*Chuckwalla's Delight*
Boerhavia sp.	*Spiderling*
Boerhavia coccinea	*Scarlet spiderling*
Boerhavia erecta	*Erect Spiderling*
Boerhavia gracillima	*Slimstalk spiderling*
Boerhavia wrightii	*Largebract spiderling*
Boerhavia intermedia	*Five-wing spiderling*
Bouteloua aristidoides	*Needle Grama*
Bouteloua barbata	*Six Weeks Grama*
Bowlesia incana	*Hoary Bowlesia*
Brassica tournefortii	*Sahara Mustard*
Bromus rubens	*Red Brome*
Bromus sp.	*Brome*
Calibrachoa parviflora	*Seaside petunia*
Camissonia californica	*California suncup*
Castilleja exserta	*Purple Owl's Clover*
Cenchrus ciliaris	*Buffelgrass*
Chaenactis stevioides	*Desert pincushion*

Chilopsis linearis	*Desert Willow*
Cryptantha sp. (angustifolia)	*Narrow leaved Cryptantha*
Cryptantha barbigera	*Bearded Cryptantha*
Cryptantha decipiens	*Gravelbar Cryptantha*
Cryptantha muricata	*Pointed Cryptantha*
Cylindropuntia acanthocarpa*	*Buckhorn Cholla*
Cylindropuntia bigelovii	*Teddy Bear Cholla*
Cylindropuntia leptocaulis*	*Pencil Cholla*
Cylindropuntia sp.	*Cholla*
Cycas sp.	*Cycad*
Cynodon dactylon	*Bermuda Grass*
Cyperus elegans	*Royal flatsedge*
Cyperus eragrostis	*Tall flatsedge*
Cyperus involucratus	*Umbrella Plant*
Cyperus odoratus	*Fragrant flatsedge*
Cyperus sp.	*Flatsedge*
Datura wrightii	*Sacred Datura*
Distichlis spicata	*Desert Saltgrass*
Echinochloa crus-galli	*Barnyard Grass*
Eleocharis geniculata	*Bent Spikerush*
Eclipta prostrata	*False Daisy*
Encelia farinosa	*Brittlebush*
Eragrostis spectabilis	*Purple Lovegrass*
Eragrostis pectinacea	*Tufted Lovegrass*
Erigeron candensis	*Horseweed*
Eriodictyon angustifolium	*Narrowleaf Yerba Santa*
Eriogonum defluxum	*Skeletonweed*
Erodium cicutarium	*Stork's Bill*
Eschscholzia californica	*California Poppy*
Eucalyptus camaldulensis	*River red gum*
Euphorbia albomarginata	*Whitemargin Sandmat*
Chamaesysce sp.	*Sandmat*
Chamaesyce hyssopifolia	*Hyssopleaf Sandmat*
Euphorbia maculata	*Spotted Spurge*
Euphorbia melanadenia	*Red Gland Spurge*
Euphorbia polycarpa	*Common Sandmat*
Eustoma exaltatum	*Catchfly Prairie Gentian*
Festuca ovina	*Sheep's Fescue*

Gentianella sp.	*Dwarf Gentians*
Gilia stellata	*Star Gilia*
Helianthus annuus	*Sunflower*
Heliotropium curassavicum	*Alkali Heliotrope*
Herniaria hirsuta	*Hairy Rupturewort*
Hordeum murinum	*Mouse Barley*
Hydrocotyle verticillata	*Pennywort*
Lactuca serriola	*Milk Thistle*
Larrea tridentata*	*Creosote*
Lemna sp.	*Duckweeed*
Lemna minor	*Duckweed*
Leptochloa fusca	*Mexican Sprangletop*
Linanthus bigelovii	*Bigelow's Linanthus*
Ludwigia peploides	*Floating Primrose Willow*
Ludwigia erecta	*Yerba de Jicotea*
Lupinus sparsiflorus	*Broadleaf Lupine*
Lycium sp.	*Wolfberry*
Lythrum californicum	*California Loosestrife*
Malva parviflora	*Little Mallow (Cheeseweed)*
Melilotus indicus	*Yellow Sweet Clover*
Mentzelia albicaulis	*Small Flowered Blazing Star*
Mentzelia sp.	*Small Flowered Blazing Star*
Nicotiana glauca	*Tree tobacco*
Nicotiana obtusifolia	*Desert tobacco*
Oncosiphon pilufer	*Stinknet*
Opuntia sp.*	*Prickly Pear*
Parietaria hespera	*Pellitory*
Parkinsonia aculeata	*Jerusalem Thorn*
Parkinsonia florida	*Blue Palo Verde*
Parkinsonia microphylla*	*Little Leaf Palo Verde*
Pectocarya platycarpa	*Broadfruit Combseed*
Pectocarya recurvata	*Curvenut Combseed*
Pennisetum setaceum	*Fountain Grass*
Persicaria hydropiperoides	*Swamp Smartweed*
Persicaria maculosa	*Redshank*
Phacelia distans	*Distant Scorpionweed*
Phacelia crenulata	*Notch-leaf Scorpionweed*
Phoradendron californicum	*Mesquite Mistletoe*

Plagiobothrys tenellus	*Slender Popcornflower*
Plagiobothrys arizonicus	*Arizona Popcornflower*
Plantago patagonica	*Woolly Plantain*
Pluchea odorata	*Marsh Fleabane*
Pluchea sericea	*Arrowweed*
Polygonum aviculare	*Prostrate Knotweed*
Polypogon monspeliensis	*Rabbitsfoot Grass*
Populus fremontii*	*Freemont Cottonwood*
Portulaca oleracea	*Common Purslane*
Prosopis chilensis	*Chilean Mesquite*
Prosopis glandulosa*	*Honey Mesquite*
Prosopis velutina*	*Velvet Mesquite*
Prosopis pubescens*	*Screwbean Mesquite*
Pseudognaphalium stramineum	*Cottonbatting Plant*
Ricinus communis	*Castor Bean*
Rumex dentatus	*Toothed Dock*
Salix gooddingii	*Goodingg's Willow*
Samolus sp.	*Brookweed*
Sarcostemma sp.	*Dogbane/milkweed*
Schismus arabicus	*Arabian Schismus*
Schoenoplectus acutus	*Tule*
Schoenoplectus americanus	*Three-Square Bulrush*
Schoenoplectus californicus	*California Bullrush*
Senna covesii	*Desert Senna*
Sisymbrium irio	*London Rocket*
Solanum elaeagnifolium	*Silverleaf Nightshade*
Sonchus asper	*Spiny-leaved Sowthistle*
Sonchus oleraceus	*Common Sowthistle*
Sporobolus sp.	*Sacaton*
Sporobolus airoides	*Alkali Sacaton*
Stemodia durantifolia	*Purple Stemodia*
Stephanomeria pauciflora	*Brownplume Wirelettuce*
Stylocline micropoides	*Woolyhead Neststraw*
Symphyotrichum expansum	*Saltmarsh Aster*
Tamarix chinensis/ramosissima	*Saltcedar*
Tidestromia lanuginosa	*Wooly Tidestromia*
Tribulus terrestris	*Puncture Vine*
Typha domingensis	*Southern Cattail*

Typha latifolia	*Common Cattail*
Veronica anagalis-aquatica	*Water Speedwell*
Vitex agnus-castus	*Chaste Tree*
Vulpia octoflora = Festuca octoflora	*Sixweeks Grass*
Washingtonia robusta	*Skyduster (Mexican Fan Palm)*
Xanthium strumarium	*Rough Cockleburr*

B.2 REPTILES AND AMPHIBIANS (HERPETOFAUNA)

Anaxyrus punctatus	*Red-spotted Toad*
Anaxyrus woodhousii	*Woodhouse's Toad*
Apalone spinifera	*Spiny Softshell*
Callisaurus draconoides	*Zebra-tailed Lizard*
Chrysemys picta	*Painted Turtle*
Cnemidophorus tigris	*Tiger Whiptail*
Coleonyx variegatus	*Western Banded Gecko*
Cophosaurus texanus	*Greater Earless Lizard*
Crotalus atrox	*Western Diamond-backed Rattlesnake*
Dipsosaurus dorsalis	*Desert Iguana*
Hemidactylus turcicus	*Mediterranean Houe Gecko*
Lampropeltis getula	*Common Kingsnake*
Leptotyphlops (Rena) humilis	*Western Threadsnake*
Lithobates berlandieri	*Rio Grande Leopard Frog*
Lithobates catesbeianus	*American Bullfrog*
Masticophis flagellum	*Coachwhip*
Salvadora hexalepis	*Western Patch-Nosed Snake*
Sceloporus magister	*Desert Spiny Lizard*
Thamnophis marcianus	*Checkered Gartersnake*
Trachemys scripta	*Pond Slider*
Urosaurus graciosus	*Long-tailed Brush Lizard*
Urosaurus ornatus	*Ornate Tree Lizard*
Uta stansburiana	*Common Side-blotched Lizard*

B.3 BIRDS

Accipiter cooperii	*Cooper's Hawk*
Accipiter striatus	*Sharp-shinned Hawk*
Actitis macularius	*Spotted Sandpiper*
Aeronautes saxatalis	*White-throated Swift*
Agapornis roseicollis	*Rosy-faced Lovebird*
Agelaius phoeniceus	*Red-winged Blackbird*
Amphispiza bilineata	*Black-throated Sparrow*

Anas carolinensis	*American green-winged teal*
Anas platyrhynchos	*Mallard*
Anser caerulescens	*Snow Goose*
Anthus rubescens	*American pipit*
Archilochus alexandri	*Black-chinned Hummingbird*
Ardea alba	*Great Egret*
Ardea herodias	*Great Blue Heron*
Auriparus flaviceps	*Verdin*
Aythya collaris	*Ring-necked Duck*
Branta canadensis	*Canada Goose*
Buteo jamaicensis	*Red-tailed Hawk*
Buteo lineatus	*Red-shouldered Hawk*
Butorides virescens	*Green Heron*
Calidris minutilla	*Least Sandpiper*
Callipepla gambelii	*Gambel's Quail*
Calypte anna	*Anna's Hummingbird*
Calypte costae	*Costa's Hummingbird*
Campylorhynchus brunneicapillus	*Cactus wren*
Cardellina pusilla	*Wilson's Warbler*
Cardinalis cardinalis	*Northern Cardinal*
Cathartes aura	*Turkey Vulture*
Catharus guttatus	*Hermit Thrush*
Charadrius vociferus	*Killdeer*
Chondestes grammacus	*Lark Sparrow*
Chordeiles acutipennis	*Lesser Nighthawk*
Circus hudsonius	*Northern Harrier*
Cistothorus palustris	*Marsh Wren*
Colaptes auratus	*Northern Flicker*
Colaptes chrysoides	*Gilded Flicker*
Columba livia	*Rock Pigeon*
Columbina inca	*Inca Dove*
Contopus sordidulus	*Western Wood-Pewee*
Coragyps atratus	*Black Vulture*
Corvus corax	*Common Raven*
Egretta thula	*Snowy Egret*
Empidonax oberholseri/hammondii	*Dusky/Hammond's Flycatcher*
Empidonax wrightii	*Gray Flycatcher*
Eremophila alpestris	*Horned Lark*

Falco peregrinus	*Peregrine Falcon*
Falco sparverius	*American Kestrel*
Fulica americana	*American Coot*
Gallinago delicata	*Wilson's Snipe*
Gallinula galeata	*Common Gallinule*
Geococcyx californianus	*Greater Roadrunner*
Geothlypis tolmiei	*MacGillivray's Warbler*
Geothlypis trichas	*Common Yellowthroat*
Haemorhous mexicanus	*House Finch*
Haliaeetus leucocephalus	*Bald Eagle*
Himantopus mexicanus	*Black-necked Stilt*
Hirundo rustica	*Barn Swallow*
Icteria virens	*Yellow-breasted Chat*
Icterus bullockii	*Bullock's Oriole*
Icterus cucullatus	*Hooded Oriole*
Ixobrychus exilis	*Least Bittern*
Junco hyemalis	*Dark Eyed-Junco*
Lanius ludovicianus	*Loggerhead Shrike*
Mareca americana	*American Wigeon*
Mareca strepera	*Gadwall*
Megaceryle alcyon	*Belted Kingfisher*
Melanerpes uropygialis	*Gila Woodpecker*
Melospiza lincolnii	*Lincoln's Sparrow*
Melospiza melodia	*Song Sparrow*
Melozone aberti	*Abert's Towhee*
Melozone fusca	*Canyon Towhee*
Mergus merganser	*Common Merganser*
Mimus polyglottos	*Northern Mockingbird*
Molothrus ater	*Brown-headed Cowbird*
Myiarchus cinerascens	*Ash-throated Flycatcher*
Myiarchus tyrannulus	*Brown-crested Flycatcher*
Nycticorax nycticorax	*Black-crowned Night Heron*
Oreothlypis celata	*Orange-crowned Warbler*
Oreothlypis luciae	*Lucy's Warbler*
Pandion haliaetus	*Osprey*
Parabuteo unicinctus	*Harris's Hawk*
Passer domesticus	*House Sparrow*
Passerculus sandwichensis	*Savanna Sparrow*

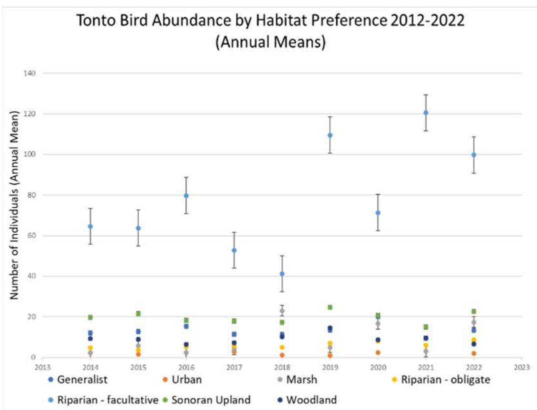
Passerina amoena	*Lazuli Bunting*
Passerina caerulea	*Blue Grosbeak*
Pelecanus erythrorhynchos	*American White Pelican*
Petrochelidon pyrrhonota	*Cliff Swallow*
Phainopepla nitens	*Phainopepla*
Phalacrocorax auritus	*Double-crested Cormorant*
Phalacrocorax brasilianus	*Neotropic Cormorant*
Pheucticus melanocephalus	*Black-headed Grosbeak*
Picoides scalaris	*Ladder-backed Woodpecker*
Pipilo chlorurus	*Green-tailed Towhee*
Pipilo maculatus	*Spotted Towhee*
Piranga ludoviciana	*Western Tanager*
Piranga rubra	*Summer Tanager*
Plegadis chihi	*White-faced Ibis*
Podilymbus podiceps	*Pied-billed Grebe*
Polioptila caerulea	*Blue-gray Gnatcatcher*
Polioptila melanura	*Black-tailed Gnatcatcher*
Porzana carolina	*Sora*
Pyrocephalus obscurus	*Vermilion Flycatcher*
Quiscalus mexicanus	*Great-tailed Grackle*
Regulus calendula	*Ruby-crowned Kinglet*
Salpinctes obsoletus	*Rock Wren*
Sayornis nigricans	*Black Phoebe*
Sayornis saya	*Say's Phoebe*
Selaphorus playcercus	*Broad-tailed Hummingbird*
Setophaga auduboni	*Audubon's Warbler*
Setophaga coronata	*Yellow-rumped Warbler*
Setophaga nigrescens	*Black-throated Gray Warbler*
Setophaga occidentalis	*Hermit Warbler*
Setophaga petechia	*Yellow Warbler*
Setophaga townsendi	*Townsend's Warbler*
Sialia mexicana	*Western Bluebird*
Spatula clypeata	*Northern Shoveler*
Sphyrapicus nuchalis	*Red-naped Sapsucker*
Spinus pinus	*Pine Siskin*
Spinus psaltria	*Lesser Goldfinch*
Spizella passerina	*Chipping Sparrow*
Stelgidopteryx serripennis	*Northern Rough-winged Swallow*

Streptopelia decaocto	*Eurasian Collared-Dove*
Sturnella neglecta	*Western Meadowlark*
Sturnus vulgaris	*European Starling*
Thryomanes bewickii	*Bewick's Wren*
Toxostoma crissale	*Crissal Thrasher*
Toxostoma curvirostre	*Curve-billed Thrasher*
Tringa melanoleuca	*Greater Yellowlegs*
Troglodytes aedon	*House Wren*
Turdus migratorius	*American Robin*
Tyrannus verticalis	*Western Kingbird*
Tyto alba	*Barn Owl*
Vireo bellii	*Bell's Vireo*
Vireo cassinii	*Cassin's Vireo*
Vireo gilvus	*Warbling Vireo*
Vireo huttoni	*Hutton's Vireo*
Vireo plumbeus	*Plumbeous Vireo*
Vireo vicinior	*Gray Vireo*
Xanthocephalus xanthocephalus	*Yellow-headed Blackbird*
Zenaida asiatica	*White-winged Dove*
Zenaida macroura	*Mourning Dove*
Zonotrichia leucophrys	*White-crowned Sparrow*

APPENDIX C

ALTERNATE VISUALIZATIONS OF ANIMAL COMMUNITY COMPOSITION

In Section 3.2 (Site Specific Results), I presented bird and herpetofauna communities at each site with stacked area charts to display both the abundance of each species or habitat preference guild and the overall abundance at that site. A scatter plot allows greater precision in interpreting differences in species or guild populations but is harder to interpret for overall abundance. In this appendix, I included scatter plots of the same data to provide a different perspective on the composition of bird and plant communities at the case study sites.



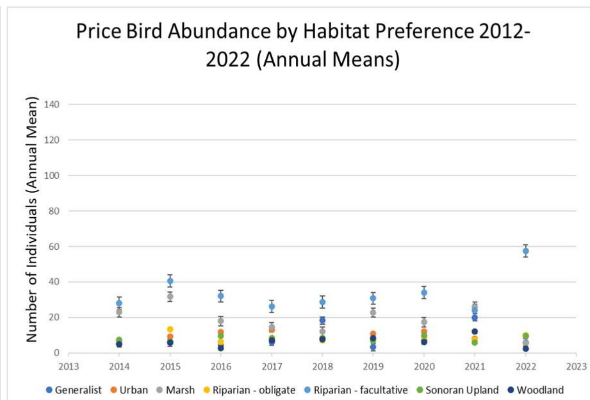
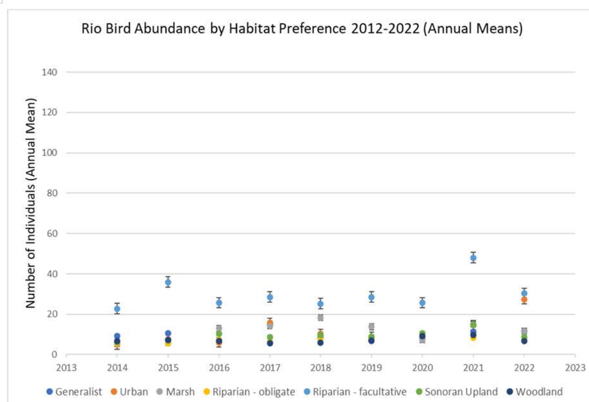
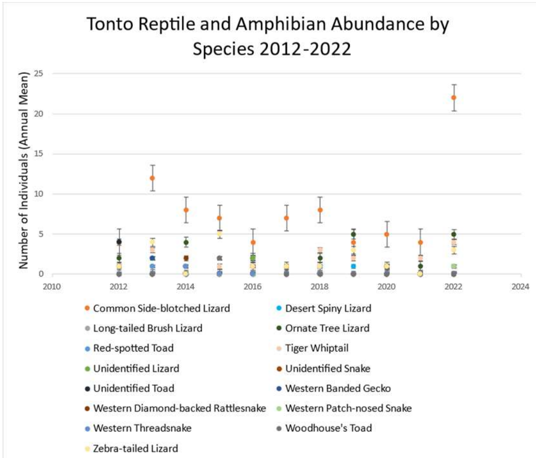
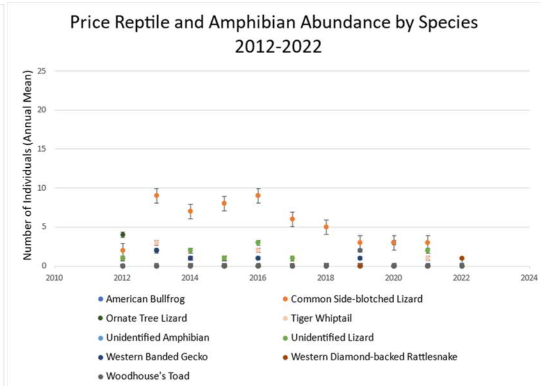


Figure 24: Bird Abundance by Habitat Preference for All Sites. Error bars are Standard error. Note that facultative riparian birds are the largest group at all sites, but at Tonto the second largest group is Sonoran upland birds while at Price the second largest group is Marsh birds. This is consistent with more abundant upland flora and smaller marsh patches at Tonto, a transition linked to herbivory and drought.







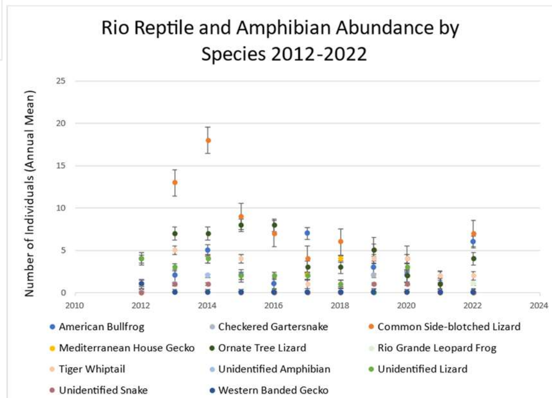


Figure 25: Reptile and amphibian abundance by species for all sites. Tonto supported more species and higher abundance, including species unique to that study site. The number of individuals detected at Price has declined, which could be a result of abundant vegetation obscuring observers' view or urban pressures such as predation by cats and increased heat from urban heat island effect. The only individual detected at Price in 2022 was a Western Diamond-Backed Rattlesnake. Rio Salado supported a range of species, including many frogs and geckos, which have different habitat requirements than many of the lizards and snakes recorded at Tonto; this different composition reflects the higher cover, habitat complexity, and water availability at Rio Salado.