Chapter 6. It's Not All Bad News—Riparian Areas in the Anthropocene

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Introduction

An abundance of information, some of which is included in other chapters in these volumes, documents and laments the historic loss of or changes to riparian ecosystems. Historic impacts to most riparian organisms, ranging in size from cottonwood trees to microbes, are fairly well documented. Causes of these changes are also well documented or speculated upon based on the best available information. It is clear that the world, and specifically the riparian world, has changed because of human activities. It appears likely that changes will continue to occur as human activities continue, and that our impacts are sufficient to cause the planet to enter a new era of geology, atmospheric chemistry, and biology termed the Anthropocene (Crutzen and Stoermer 2008). Most of the changes that have occurred historically are generally considered "bad" because they involve a loss of biological communities that we usually consider "good." A small industry has developed involved in the protection of remaining riparian areas and wetlands and restoration or creation of new ones to compensate for historic losses and solve other problems.

This industry has met with mixed results, but complete restoration or creation of fully functional self-maintaining wetlands has probably not been achieved and may not be entirely desirable (Karpiscak and others 2004; Willott 2004). This industry is largely supported by funding by the U.S. Army Corps of Engineers and Environmental Protection Agency for restoration or wastewater treatment projects, although some may be supported by private, local, or regional sources. Much effort is currently being directed toward intentionally "restoring" riparian communities, or at least the most conspicuous desirable indicators of those communities, and protecting those remaining riparian communities that appear to be somewhat intact. These efforts continue to lead to a greater understanding of the nature of riparian communities. Many components from microbial to landscape and planetary are necessary to make healthy ecosystems.

Historically throughout the southwestern United States, rainwater sank into permeable ground or ran off impermeable or saturated surfaces into natural channels. These confluenced with increasingly larger streams until eventually the water sank into the streambed or ran to a sea or natural lake. Riparian communities developed along these natural drainage ways. The natural drainage scheme has been diverted, obstructed, reoriented, eliminated, or otherwise altered by human activities for thousands of years. In the most recent period of the Anthropocene, the permeability of the watershed substrate has been changed by overgrazing of watersheds, fires, invasion of alien plant species, trampling by livestock and people, and paving. Drainage ways have been channeled, blocked, driven underground, piped, dammed, and diverted. Especially in urban areas, what comes down from the sky no longer follows natural paths but travels through a maze of structures designed (or not) to put it somewhere else.

One could lament the loss of the natural riparian communities that were once part of the natural hydrologic pathways. One could also learn to appreciate some of the ways people and nature have combined to create new and different (and, frankly, often inferior) riparian communities. Here, my purpose is to look at some examples of riparian communities that have been developed, intentionally or not, in association with human attempts to deal with the hydrologic cycle. Most of what follows is based on personal observations over several decades, and may not be documented or supported by scientific or other literature. When appropriate references are available, they are given.

Wastewater Treatment Plants—A Source of Water

Example 1: Santa Cruz River Downstream From Nogales and Tucson

The Santa Cruz River was historically an interrupted perennial stream (Stromberg and others 2012; Webb et. al. 2014) that began in the Canelo Hills of southern Arizona, passed briefly into Mexico, and then made a northward turn to run some 200 miles to join the Gila River. Today, the same generalization can be made, but historically wet reaches have become dry, except during brief spates, and historically dry reaches are now perennially wet. Detailed descriptions of the historic river and anthropogenic changes to it are given in many sources, most notably the recent volume by Webb and others (2014) that includes a compilation of historic records, including photographs and descriptions by early settlers and naturalists. More recent, frequently updated descriptions of conditions can be found on the website of the Sonoran Institute (https://sonoraninstitute.org). Groundwater pumping and watershed changes are primary reasons for the drying of the historically wet reaches and treated urban sewage effluent is the sole reason for some reaches to be perennially wet today.

Over the past two decades, a growing body of literature examining the currently wet reaches has developed and is expected to expand as additional studies are conducted. Much of this literature is in the category of “gray literature,” consisting of agency and consulting reports, synopses, or abstracts of meeting presentations, theses, dissertations, and web-based information. A review of this literature and description of conditions in 2013 was done by Pima County (2013). Updates of many current research projects and conditions are available from the Sonoran Institute website (https://sonoraninstitute.org) or by following leads on that website. It is clear that a new and dynamic river has emerged, differing greatly from the former in flow regime, water quality, substrate qualities, bank morphology, wildlife and plant uses and distribution, and human uses. Any description of “current” conditions will be of transitory value, and the situation will change, sometimes quite rapidly. This brief section describes conditions as they were primarily during the first decade of the 21st century. Several restoration projects of varying scales and approaches are in progress at this time (2018) and more are likely to be developed.

In 2018, there were two perennially wet reaches, one carrying effluent from the Nogales International Treatment Plant in Nogales, Arizona (Upper Santa Cruz), the other carrying effluent from treatment plants serving the Tucson area (Lower Santa Cruz).

Effluent input began on the Upper Santa Cruz in 1951 and on the Lower Santa Cruz during the 1970s, when the urban populations were less than half of present, and when treated effluent discharge into rivers was considered an expedient way to get rid of a problem. There were few regulations and little attention directed toward the discharge. Water flow in these reaches is subject to daily and seasonal fluctuations, depending on water use in the areas served by the treatment plants. Longer-term changes occur as the urban populations grow, demand for effluent for other uses varies, and sewage treatment processes develop. The amount of effluent in the Upper Santa Cruz was greatly reduced in 2012, changed in quality in 2013, and is expected to be practically eliminated as new technology is applied in Mexico. Added to input are occasional floods following precipitation events in which urban stormwater runoff and drainage from undeveloped portions of the watershed are added to the effluent flow.

Water is removed from these reaches by penetration into the substrate, diversion for irrigation, and evapotranspiration by vegetation. The depth to groundwater has been lowered so much by groundwater withdrawal that there is little or no immediate connection between the deep aquifer and surface water, and the zone of water availability to plants is limited to the immediate vicinity of flow channels. Water availability to plants and subsurface recharge may be reduced by buildup of a clogging coating of relatively impermeable material (schmutzdecke) caused by physical, chemical, and biological processes. This material may be removed at unpredictable intervals by flooding caused by summer monsoon storms. If there is no flooding, then riparian vegetation may die. This is an "inherently unstable" situation, which may result in rapid loss of riparian communities if no human intervention occurs to break up the clogging layer (Treese and others 2009). Innovations at the Nogales treatment plant in 2009, and subsequently, have led to an improvement in water quality, reduction of schmutzdecke, and return of native Gila topminnows (*Poeciliopsis occidentalis*) to a portion of the currently wet Upper Santa Cruz (U.S. National Park Service 2015).

Water quality is different from that of natural water sources and varies considerably with distance from the inlets, natural input events, changes in human population and water use, and sewage processing technology. A change in water quality for the Lower Santa Cruz followed the 2014-15 activation of new technology that is part of the Regional Optimization Master Plan. This resulted in a decrease of schmutzdecke and an increase of diversity of aquatic macroinvertebrates and fish including Gila topminnows (Sonoran Institute 2017). Prior to this change, water quality was such that many species of aquatic animals and plants that formerly lived in wet reaches of the river could not survive, whereas others, including nonnative invasives, thrived.

Propagules of native species that formerly inhabited the area may not be available, either because the currently wet areas never had them, or because populations have been extirpated from the watershed. Temperature is higher at effluent inlets than downstream. Nitrogen compounds are high near effluent inlets and attenuate downstream. Ammonia levels may be toxic to fish, amphibians, and invertebrates for a portion of the stream. Benthic macroinvertebrate communities vary with distance from inlets and concomitant changes in several parameters of water quality (Boyle and Fraleigh 2003), with taxa that are tolerant of pollutants present near the inlets and diminishing downstream, and intolerant taxa absent near inlets and becoming established downstream. Benthic macroinvertebrate communities are greatly limited by substrate condition (mostly sand and schmutzdecke, little gravel, few cobbles, very few boulders). They are also limited by flow amounts and distributions, which vary through a wide range hourly, daily, and seasonally.

Microbial communities, including potentially pathogenic microbes, may be greatly influenced by introduction of propagules and living organisms in effluent and by variation in conditions downstream from inlets (Duran and Spencer 2004). Unique mixtures of chemicals, including biologically active compounds such as pharmaceuticals and endocrine disruptors, occur and may impact the plants and animals in and along the stream.

Riparian vegetation, including cottonwood-willow forests, have developed in patches that formerly had only xeroriparian scrub, and a few areas (near Tubac and Tumacácori National Historical Park) of previously developed riparian forest and woodland have been nourished and enhanced by the effluent. Through much of the currently wet reach of the Lower Santa Cruz, the banks have been deeply incised and are now lined with soil cement to prevent bank erosion and flooding. Although the newly developed riparian areas have many characteristics of historic pristine conditions, they also differ in that they have a mix of native and nonnative plants and animals and lack many species that were historically found in the wet reaches of the river.

For the most part, riparian trees are smaller in stature under the new conditions than those found in more natural riparian areas, but that may be because they are younger. Native trees include Fremont's cottonwood (*Populus fremontii*), Goodding's willow (*Salix gooddingii*), velvet mesquite (*Prosopis velutina*), and blue palo verde (*Parkinsonia florida*). Nonnative trees include "Chilean" mesquite (*Prosopis* sp.) and possible hybrids with natives, Jerusalem thorn (*Parkinsonia aculeata,* apparently nonnative in this situation), athel tamarisk (*Tamarix aphylla*), and saltcedar (*Tamarix ramosissima*). The mix of species in any given reach may be unique and may change over time.

Because the depth to a zone of permanent available water is greater than the depth to which roots can reach, if the flow is reduced or changes channels slightly, riparian vegetation may be cut off from water and die. Changes in effluent amounts released by treatment plants may have profound impacts on vegetation. Minor channel changes caused by floodwaters rearranging the substrate can result in loss of blocks of riparian vegetation. Floodwaters cannot spread across a broad floodplain but are confined within soil cement walls through much of the urban area. This confinement increases the velocity of floods and damage to river bottomland vegetation when floods occur.

Many species of native birds have discovered and adapted to the newly established riparian areas. Some of the areas have become quite popular with local birders and appear on bird guidebooks and websites. A list of species found has been growing over many years, and migrating species that are outside their normal range are frequently spotted. In a yearlong study of birds using five different sites along the effluent-dominated Lower Santa Cruz, 133 species were recorded (SWCA 2000). There were differences between sites, between survey dates on each site, and between seasons. Most of the differences between sites can be attributed to the relative composition of vegetation associations at each site. Where trees, especially Fremont's cottonwood and Goodding's willow, were dominant, native bird species typically found in native riparian habitats were present. However, because blocks of trees were narrow and most of the trees young, many species of birds typically found in large blocks of native riparian habitat were missing (e.g. yellow-billed cuckoo *Coccyzus americanus*) or rare (e.g. summer tanager *Piranga rubra*). Twenty-seven species of wading birds, shorebirds, and waterfowl were documented. Many migrating birds were observed, typically only once or twice during the year.

Other wildlife is known to use the area, including nonnative American bullfrog (*Lithobates catesbianus*), but no native frogs. Native Sonoran mud turtle (*Kinosternon sonoriense*) and nonnative spiny softshell turtle (*Apalone spinifera*) and most native reptiles appropriate for riparian habitats are present. Some mammals, both native (coyote, woodrat, cotton rat, bats) and nonnative (domestic and feral dogs and cats and cattle) were seen. Native fish (Gila topminnow) were found for the first time in decades in 2017 (Sonoran Institute 2017), but several nonnatives have been long been present, including mosquitofish (*Gambusia affinis*). Presence of bullfrogs and mosquitofish probably precludes or at least complicates potential restoration of populations of natives.

Figure 20—Riparian habitat: effluent-dominated reach of Santa Cruz River in Tucson, historically dry, currently wet. Note narrow width of riparian vegetation and soil cement bank. Photo by author.

Figure 21—Riparian habitat and multi-use trail, along the historically wet, currently dry reach of the Lower Santa Cruz River in Tucson, which is now part of a linear park with multi-use trail. Photo by Amy Gaiennie.

The existing conditions of the Lower Santa Cruz River provide a valuable resource for the human community. A paved multi-use trail runs through developed parkland along both sides of the river for much of its course through urban Tucson, and it is very heavily used by pedestrians and bicyclists (figs. 20 and 21). The larger trees, especially athel tamarisk and Fremont's cottonwood, are frequently used as campsites by homeless people. As mentioned, bird watchers find the area of interest. Long-term residents understand and appreciate the changes that have occurred, but many young people and visitors may think the current conditions are normal and natural and appreciate their protection as parkland.

Example 2: An Artificial, Intentional Riparian Site—Sweetwater Wetlands

An active domain of wetland creation is constructed wetlands for processing of sewage wastewater (Kadlac and Wallace 2009). An example is Sweetwater Wetlands, Tucson, Arizona, which was created to process water that had been used to backwash filters at the Roger Road Wastewater Treatment Plant and put that water into the reclaimed water system. Considerable planning went into the effort to create an aesthetically pleasing wetland that would allow plants to process the water through a process of filtration, settling, and biological activity. Early on in the planning process, an expert on mosquito control was hired to help design a wetland that would not be plagued by mosquitoes. Unfortunately, mosquito control recommendations were scrapped in the later stages of planning because effective mosquito control was not consistent with effective water processing, the hoped-for wildlife and aesthetic values, and the project budget.

Sweetwater Wetlands was created, planted with native wetland plants including Fremont cottonwood and cattails (*Typha latifolia*) and put into operation. It included ponds with islands for nesting birds (fig. 22), dense cattail stands for various stages of water

Figure 22—One of the ponds at Sweetwater Wetlands, February 2014. Originally used to process filter backflush water as part of an older sewage treatment system, this and adjacent ponds are currently filled with reclaimed water to provide wildlife habitat and a recreational amenity for the community. Photo by author.

processing, a complex of several ponds surrounded by a walkway and piers for wildlife viewing, interpretive signs, restrooms, a public parking lot, and a system of aquifer recharge ponds. Educational programs were developed and thousands of schoolchildren have learned about wastewater processing, wetlands, and ecology on field trips. Informative brochures and an "Activity Book and Field Guide" have been produced. Processed water from the Treatment Plant flowed out into the riverbed close to this location, and the perennial lower Santa Cruz River began here. With some adjustments, the desired water processing, wildlife, and aesthetic values were achieved, and the area has become an outstanding popular recreation area for birders and a valuable educational resource.

Over 300 species of birds have been documented at the site (City of Tucson 2016). However, a mosquito problem also developed and has required continuous expensive effort (Karpiscak and others 2004; Willott 2004). Until recently, water quality could not support fish and may have been a population sink for migrating aquatic insects. Water quality improvements since 2014 have led to establishment of a dense population of mosquitofish and many species of aquatic insects that have probably greatly reduced the mosquito population. The sewage processing method changed in 2014, and Sweetwater Wetlands was no longer needed for its original function. Today, if the wetlands were allowed to dry and be removed, there would probably be a significant public outcry over the loss of recreational and educational benefits. Maintaining the wetlands as a park has become separate from the reason for their original creation because water treatment technology has changed. Continuous active maintenance and management are necessary to prune trees, keep pathways and structures in good condition, thin cattails, and prevent mosquitoes.

Urban Runoff—A Source of Water

In the urban environment, stormwater is often directed through a series of drains, sewers, canals, and culverts to run off eventually to a designated depository where it can enter its natural pathway or be used for aquifer recharge or other uses. Some of the structures created to handle urban stormwater can become important wildlife habitat if they are allowed or created to become so. Retention basins are designed to manage stormwater runoff to prevent flooding and downstream erosion and to improve water quality downstream. Retention basins are, at best, artificial lakes with vegetation around the perimeter, designed to include a permanent pool of water. Detention basins are designed to store water temporarily after a storm, but eventually to empty at a controlled rate to a downstream water body. Infiltration or recharge basins are designed to direct stormwater (or other water) to groundwater through permeable soils.

Vegetation may be intentionally planted or volunteer around the margins of the ponds or appear as emergent or aquatic plant communities. These utilitarian stormwater drainage features can be managed to improve the neighborhood and may be seen as valuable amenities, or they may be mismanaged to become major nuisances as mosquito breeding sites or other pest habitats.

The U.S. Fish and Wildlife Service, in cooperation with the Arizona Game and Fish Department and local government agencies, has developed a Safe Harbor Agreement for two species of endangered fish, Gila topminnow and desert pupfish (*Cyprinodon macularius*) that permits placing these fish in retention basins and other artificial bodies of water (Duncan and Voeltz 2005). As of early 2016, this agreement has not been used for placing fish in urban retention and detention basins because of the concern with fish moving downstream to another property (D. Duncan, U.S. Fish and Wildlife Service, personal communication). Fish have been utilized to control mosquitoes and other nuisance insects in artificial ponds and have been successfully established under this agreement in a few other artificial habitats. Also, their use in compliance with the terms of the Safe Harbor Agreement has expanded the range of remaining populations of these endangered fish and greatly increased the number of individuals of each species, which benefits the species especially if anything impacts the few remaining natural habitats.

Example: Kino Environmental Restoration Project (KERP)

An example of a detention basin developed for maximizing habitat values and minimizing nuisances is the Kino Environmental Restoration Project in Tucson, Arizona (Pima County 2015). Urban stormwater runoff from approximately 18 square miles around the Davis Monthan Air Force Base and the City of Tucson runs through a series of drainages, mostly concrete-lined box culverts or ditches, to collect in the Tucson (Ajo Road) Detention Basin. Prior to the inception of this project, the basin of approximately 50 acres was surrounded by concrete with a mostly mud substrate. Often the basin was dry, or filled with stagnant water and debris, and provided excellent mosquito larval habitat and dense weeds. In the mid-1990s, the U.S. Army Corps of Engineers, Pima County, and the Pima County Flood Control District collaborated in a cooperative agreement to create the Ed Pastor Kino Environmental Restoration Project (KERP). The goal was to create a facility that would meet three primary purposes: create native ecosystems, harvest urban stormwater, and control flooding. Elimination of mosquitoes was also an important consideration, as was elimination of trash dumping.

The project today is managed by the Kino Sports Complex/Stadium District in cooperation with Pima County departments, such as the Health Department, Regional Flood Control District, Department of Transportation, and the Regional Wastewater Reclamation Department, in addition to a number of State agencies to ensure KERP meets the State and Federal guidelines set forth for an environmental habitat. The final footprint of the KERP covers 141 acres and contains 28 acres of riparian and open water including: a 5.6-acre, 50-foot deep pond; 21 acres of grassland, mesquite bosque, marsh and upland vegetation; three short stream courses; and 92 acres that include flood control structures, a basin earthen berm, and a 2.2-mile recreational path that surrounds the basin (figs. 23 and 24).

Native plants associated with wetlands and riparian areas, as well as upland habitats, have been planted and are irrigated by a combination of floodwaters gathered by the basins and reclaimed sewage effluent. Some invasive plant species have come into the area but are managed. A pumping and valve system circulates and mixes reclaimed and stormwater within the basin. Stormwater coming into the project first passes a debris basin equipped with a trash rack to retain sediment and trap floating objects. It then passes into lined storage ponds that retain the runoff. Two small weirs and a weir gate regulate the flow of water into the deep pond. Water is circulated along the three stream courses that drain into the ponds, and cooler water is pumped from the bottom of the 50-foot pond to the top of the stream courses to improve water quality and aid with vector control. Water levels fluctuate depending on the availability of stormwater, and much of the area is designed to hold large volumes of rapidly arriving water during wet periods and survive as upland in dry periods. During periods of extended dryness, treated effluent (aka

Figure 23—Riparian habitat: Kino Environmental Restoration Project, deep pond and vegetation, February 2014. The pond was created primarily a receptacle for stormwater runoff from the upstream urban area, and is managed, in part, to provide wildlife habitat and as a recreational amenity. Its design and management allow for rapid filling following storm events and minimization of mosquito habitat. Photo by author.

Figure 24—Riparian habitat: Kino Environmental Restoration Area, shallow pond and vegetation, February 2014. This pond is off the stormwater channel, so is not subject to rapid inundation, but is filled by water intentionally diverted from the large pond for the purposes of aquifer recharge, water storage, and wildlife habitat. Photo by Amy Gaiennie.

reclaimed water) is purchased from Tucson Water to maintain pond levels and protect habitats. A 16-inch reclaimed water pipeline feeds water into the pond. In addition, the open water areas and marsh can be fed by three additional pipelines at KERP.

Harvested stormwater, when available, can be a low-cost alternative to purchasing and using groundwater and reclaimed water. This project has yielded approximately 19 million gallons per year of usable irrigation water (10-year average, range 0 to 39 million gallons). The water has been used to irrigate the basin's vegetation, the adjacent Kino Sports Complex ballpark and athletic fields, road median landscaping and easements, and landscaping for nearby public buildings. The project has become a popular recreational site and birding area, although access to the most interesting habitats is limited, and most viewing must be done from a distance. A casual visitor may see an assortment of birds representative of the variety of ecological communities present in the project, including migratory waterfowl, shorebirds, and wading birds. Some informative signs have been posted, and most have survived vandalism. Discussions are ongoing between agencies regarding placing native fish under the Safe Harbor Agreement.

Areas With Water Supplied by Agricultural Irrigation

Agriculture has historically been the largest destroyer of riparian habitat, directly by conversion of riparian forests and woodlands to croplands, and indirectly by damming streams and rivers to create reservoirs, reduce flooding, and manage water availability. In arid lands, riparian areas are clearly the most suitable for agriculture because the land is relatively level, close to water, and has suitable soils. In Arizona and much of the arid Southwest, the primary crops have been cotton, alfalfa, vegetables, or grass. These have replaced native woodlands with monoculture shrublands, fields of forbs, or grassland. Tree crops, primarily citrus and pecans, have created nonnative woodlands. Whereas a great deal of research has gone into studying how to grow these crops, very little has looked at the ecological effects of the conversion of native riparian areas to croplands and the novel communities of wildlife and native plants that develop.

Ohmart and others (1985) found that agriculture created new habitats for wading, water, and shorebirds, and that the type of agricultural development and crops grown were important in determining species composition and population sizes. Conine and others (1978) found that some riparian bird species used agricultural land as foraging habitat, whereas others did not. Wells and others (1979) examined avian use of citrus orchards and found that citrus was an important habitat for doves but generally lacked flycatchers, small insectivores, and woodpeckers, which were abundant in native riparian habitat.

Obviously, birds that require trees do not do well in cotton fields and many other animals once common in native riparian communities cannot survive the conversion to agriculture. Other creatures, however, do manage to adapt in various ways, perhaps losing nest or den sites but gaining feeding areas. If nearby sites can provide the missing components (e.g., nest sites near grain fields, ditch banks, and culverts near alfalfa fields), some animals may survive and even thrive. It appears unlikely, if not impossible, that intact communities with all previously present species in healthy numbers can survive, but some agricultural crops can provide suitable habitats for many of the species native to our riparian communities.

Example: Pecan Orchards as Riparian Habitats

Kingsley (1989, 1985a,b) studied wildlife uses of a large irrigated pecan orchard along the Santa Cruz River south of Tucson (fig. 25). At the time, this was said to be the world's largest irrigated pecan orchard and consisted of approximately 2,200 hectares with tree densities varying from 59 to 119 trees per hectare. Fields were flood irrigated approximately every 2 weeks during the growing season (April-October typically). Trees were even-aged, tall, with the understory cleared of most vegetation. Stumps of removed trees sometimes sprouted and created a shrub story and a mixture of forbs and grasses were the understory. Dense tall weeds, including several species of seed-providing forbs and grasses, occurred in places along irrigation ditches and tailwaters. Slash piles consisting of pruned branches surrounded many fields and provided a structural equivalent of a dense shrub story that was utilized by some wildlife species.

Insects were abundant, most of them considered beneficial or neutral, although aphids that feed on pecans and mosquitoes that bite people were present, and outbreak populations had caused problems (Kingsley 1985a). Many aquatic insect species migrated into the flooded fields and irrigation ditches but probably could not survive and reproduce successfully since these were temporary waters. Amphibians were present and abundant, but the only species documented as successfully reproducing was Couch's spadefoot (*Scaphiopus couchi*), which can develop in transitory water lasting less than 2 weeks. Reptiles were relatively rare, probably because they cannot survive and reproduce under conditions of frequent inundation, absence of topographic diversity, or lack of some microhabitat components (Jones and Glinski 1985).

Kingsley (1989) listed 83 species of birds found in the orchard with populations ranging from rare and transitory to greater than those found in native riparian woodlands. Flycatchers and small insectivores were present, but woodpeckers were absent as nesting birds although frequently seen foraging in the orchard. Birds characteristically found in dense riparian thickets were not found. No dense midstory was present. Hole-nesting birds were not found breeding, but several were observed foraging. Tree holes were not allowed to develop.

Predatory mammals such as coyote (*Canis latrans*) and raccoon (*Procyon lotor*) and bats of several species were abundant as foragers, but burrowing mammals were generally absent, probably because they could not survive frequent inundation. No survey of mammals was conducted, so the number of small mammals is unknown. Bats foraging in pecan orchards in Texas were studied by Braun de Torrez and others (2011) and Braun de Torrez and Kunz (2009), who found bats present in pecan orchards, especially organic orchards, at higher numbers and diversity than in native juniper-mesquite woodlands and the adjacent semiarid landscape.

The orchard has been a popular place for local birders, especially those on their way to Madera Canyon, an especially popular area that is reached by a road passing through the orchard. The orchard and processing plant supported approximately 250 workers and was one of the largest industries in the area at the time. Much of the historic orchard has been converted to residential development as the communities of Sahuarita and Green Valley have grown, and the long-term plan is to phase out the orchard except in floodplain-zoned sites where agriculture may continue indefinitely.

Figure 25—Flooded pecan orchard, Green Valley Pecans, Arizona. Photo by author.

Figure 26—Century-old irrigation canal, still in use, with cottonwoods. Originally put in to irrigate an agricultural field, the canal is now part of Zion National Park. Cottonwoods apparently invaded after the canal was created and are now well established. Photo by author.

Example: Unlined Irrigation Canals as Riparian Habitat

That irrigation canals support a new riparian resource has long been considered (fig. 26). Breninger (1898 p. 128), referring to the cactus ferruginous pygmy-owl, stated: "And since trees planted by man have become large enough to afford nesting sites for woodpeckers, this Owl has gradually worked its way from the natural growth of timber bordering the rivers to that bordering the banks of irrigating canals until now it can be found in places ten miles from the rivers."

Recently, Sueltenfuss and others (2013) examined such wetlands in northern Colorado using quantitative and qualitative measures. The wetlands they examined were marsh, wet meadows, and salt flats. Eighty-nine percent of the canals examined were unlined earth. They found wetlands associated with irrigation canal leakage, pond and reservoir dam seepage, wetlands located on the fringes of reservoirs, tailwaters, ephemeral channels adjacent to canals, and a few intentionally created wetlands. They found large fluctuations in water level in wetlands to be associated with the amount of water flowing in canals, sometimes with delays of up to 50 days, and not associated with precipitation events. They found one instance in which irrigation of an adjacent field was associated with water table levels in a wetland.

The same types of wetlands have been documented in southern Arizona (K.J. Kingsley, personal observations, and Kingsley 1985a), and some have cottonwood trees or other trees and shrubs growing along and watered by them.

Johnson (1972) presented a review of changes occurring along irrigation ditches in the Phoenix area, where ditches were being converted to concrete-lined conduits or underground pipes that would not support vegetation. Water conservation by lining or burying conduits has resulted in loss of these riparian resources and is likely to continue and expand as demand for water increases and availability decreases. Many of the irrigated farmlands subsequently are converted to urban and suburban communities that may be very different ecosystems.

Example: Tailwaters

Tailwaters are wetlands created by excess irrigation and are wet areas at the low points of irrigated fields or immediately downstream from the fields. Along the Gila River in southern Arizona, some tailwater wetlands have dense thickets of tamarisk (*Tamarix* spp.) that are known to be used by nesting southwestern willow flycatchers (*Empidonax trailii extimus*) (K.J. Kingsley, personal observations). Tailwaters appear to be better habitat for this species than areas along the nearby river. Water moves slowly in these areas and provides abundant habitat for mosquitoes, which are fed upon by this endangered species, whereas the river moves too quickly to provide good mosquito habitat. In addition, tailwaters are fairly stable environments, compared to the unstable river flows, and are not as susceptible to flooding with concomitant loss of vegetation structure. Water is provided even during the worst droughts when water might not be available in the river. Several other species of riparian and wetland birds may also be observed in this environment, but the typical tailwater is an unstable habitat with a dense thicket of weeds or weed trees that is kept in an early stage of succession and affords little habitat for species that prefer large blocks of habitat or more open spacing.

Example: Abandoned Fields Persisting as Riparian Habitats

Agriculture is not always successful or permanent, and when it fails, it leaves behind land that will transform from the regular rows of monoculture crops to a hodge-podge of early succession if left to itself. More than 96,356,000 ha of farmland were abandoned in the United States in the 20th century (U.S. Department of Agriculture 1998 cited in Richter and Stutz 2002). Especially in riparian areas, however, abandoned agricultural fields can be returned to some semblance of the former natural community. Sometimes, if the area is subject to a more-or-less natural flow regime and flood timing is right, and especially if the water table has not dropped to a depth inaccessible to roots, it can grow back to cottonwood-willow forest or woodland (e.g., several historic fields along the Verde River in the Cottonwood-Camp Verde area, now included in the Verde River Greenway State Natural Area, K.J. Kingsley, personal observations). Some efforts have been made to encourage or restore riparian communities to abandoned farmland.

Of some concern in abandoned agricultural lands is contamination by chemicals, including undocumented historic chemical dumps. Other concerns are reduced water input because of increased efficiency by active agriculture, unnatural flow regime, long-term unpredictability, and possible attraction or harboring of agricultural pests. To my knowledge, none of these has been documented.

Conclusion

Little scientific attention has been directed toward the study of anthropogenic riparian areas, especially those that have been inadvertently created. Many more examples could have been selected from a wide range of sites. The number, diversity, and quality of anthropogenic riparian areas are likely to change over time as human demand for water resources increases with increasing population and aspirations for amenities. These environments warrant further study and some measures of protective management to enhance their suitability as wildlife habitat and recreational resources.

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