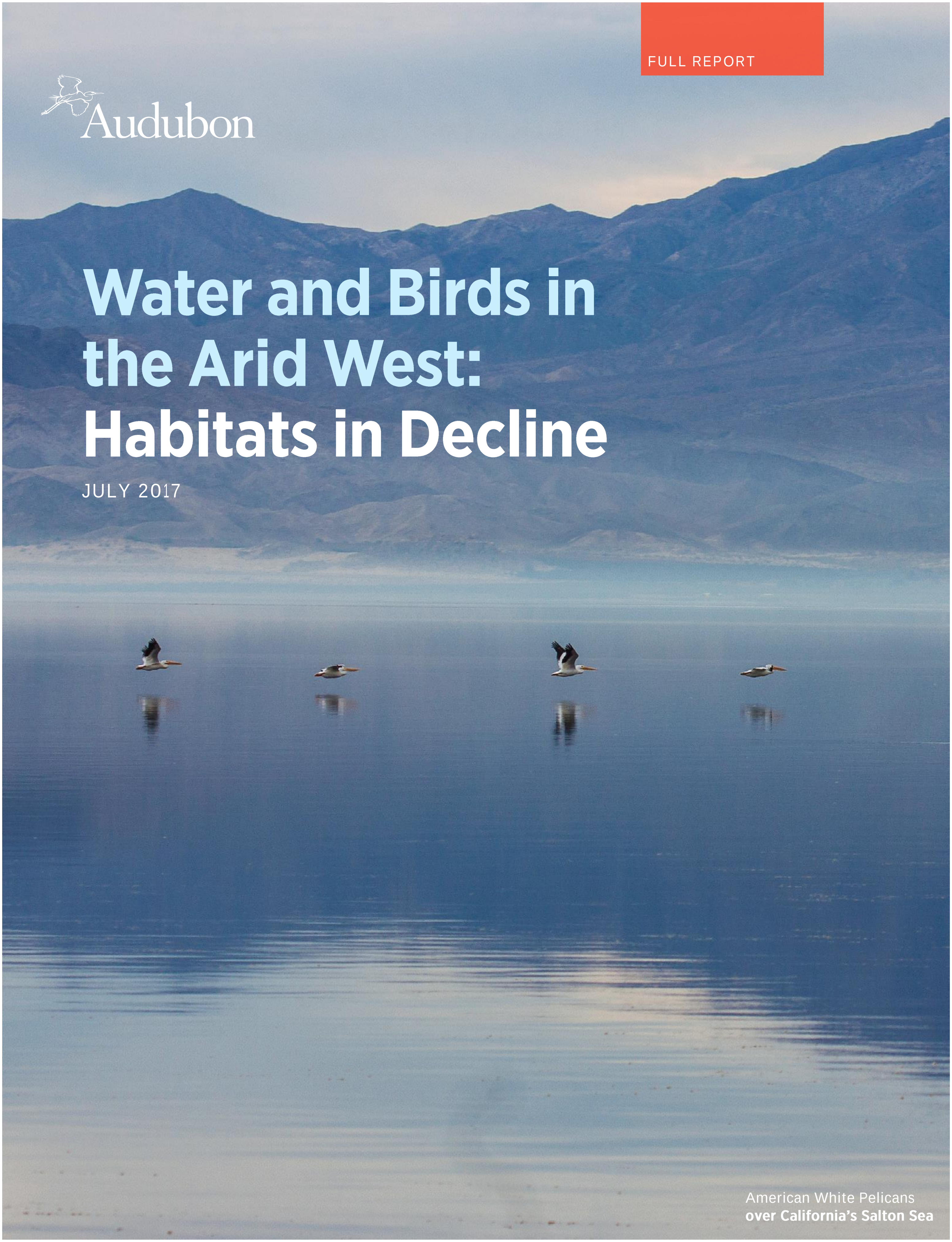
FULL REPORT

Audubon

Water and Birds in the Arid West: Habitats in Decline

JULY 2017



American White Pelicans **over California's Salton Sea**

Water and Birds in the Arid West: Habitats in Decline

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FOREWORD

Audubon's science team was putting the finishing touches on *Water and Birds in the Arid West*, when this news headline made its way to my inbox: *Lake Mead shocker: Feds now see Lake Mead levels sinking 20 feet lower by '19 than predicted just last month*.

Like that headline, this report is an urgent call to action. It's about birds, because that's Audubon's mission and our focus. But it's also about the larger western ecosystems that support not only birds, but also communities, economies, recreation, and quality of life.

Our research on the Colorado River Basin confirmed what we suspected: western riparian habitats are in trouble. The individual studies included in our analysis add up to a picture that doesn't look good for birds. Dams, diversions, and demand for water have devastated cottonwood-willow forests and other native riparian habitat which support 40% of the bird species in America's Southwest. Birds like the Yellow Warbler and Summer Tanager, once familiar sights along the Colorado River, have experienced significant regional declines. The outlook for Yuma Ridgway's Rail, Western Yellow-billed Cuckoo, and Southwestern Willow Flycatcher, all listed as federally endangered, is especially bleak if current trends continue.

What hasn't been well-documented before now is the importance of another ecosystem—western saline lakes—for millions of shorebirds and waterbirds, and the implications of its potential loss. The Great Salt Lake and the Salton Sea, along with other less well-known landlocked salt lakes that dot the West, are the unsung heroes that birds like the American Avocet and Eared Grebe depend on for survival. And here's one of the most important takeaways of our analysis: birds need all of these lakes. In fact, the western saline lakes function as a network of critical habitats. Each is a vital link on migratory pathways from winter to breeding grounds and back again. But throughout the West, saline lakes are drying up at an alarming rate, and not only eliminating bird habitat but exposing toxic dust that threatens neighboring communities.

The challenges we face on the Colorado River and across saline lakes are significant—and can seem overwhelming. The good news is that there are solutions that can sustain economic growth, a vibrant agricultural economy, and healthy rivers and lakes. It's about collaboration, innovation, and flexibility when it comes to how we use and manage our water. The Bureau of Reclamation's landmark System Conservation Pilot Program is one example. Launched in 2014, the collaborative and voluntary program has achieved more than 60,000 acre-feet in water savings through incentives to farmers for innovative agriculture irrigation systems and other projects.

Audubon has a singular and important role to play in advancing these balanced water solutions. Science, like our findings in *Water and Birds in the Arid West*, grounds our recommendations and informs our conservation planning. Passion for birds mobilizes the Audubon network of chapters and our politically diverse members and supporters. And the combination earns us credibility and influence around water management policies and decisions. It's how, working with our public and private partners, we can reshape water management so that the people, birds, and wildlife of the arid West can thrive together.

David O'Neill

Chief Conservation Officer and Senior Advisor to the CEO

WHY WATER AND BIRDS IN THE ARID WEST?

Water is the lifeblood for the places that matter most to birds. Wetlands, lakes, rivers, estuaries, and deltas are vital habitats for birds across the U.S. and around the world. Without water, these natural systems are threatened. In arid landscapes, water supports habitats along rivers and at lakes, creating oases that concentrate bird populations. People depend on water in arid regions, too, affecting how much is available for natural systems.

Audubon's work is centered on birds because if we protect birds we protect the Earth. Birds are sentinels of environmental change and unique barometers of our Earth's health due to the vast distances they travel across the hemisphere. Here, we explore the health of water-dependent ecosystems across the arid West using birds as our guide.

In the 2016-2020 strategic plan, Audubon identified Water as a core priority focused on landscapes where water scarcity and water quality are primary limiting factors for the survival of threatened and iconic birds in the Western Hemisphere. Audubon's Water Strategy engages Audubon's conservation, policy, and science teams and the Audubon network to influence water management decisions in order to balance the needs of birds and people living on or near habitats dependent on freshwater across the nation. One of the key geographies for this Water Strategy is the arid and intermountain region of the western U.S. where water is a limiting resource.

In the arid West, millions of birds from hundreds of species depend on riparian forests, wetlands, and saline lakes maintained by freshwater. Riparian forests refer to patches of deciduous forest that form along stream and rivers historically dominated by cottonwoods, willow, and mesquite. Saline lakes are landlocked waterbodies that have no outlets. Water leaves naturally through evaporation resulting in the accumulation of salts (and high water salinity) over time.

Over-tapped water resources in the arid West are causing a dangerous loss of habitat for birds. These habitats are under threat from altered flow regimes, prolonged drought, contamination, invasive species, and climate change, resulting in a crisis for many species. Without action, the decline of water resources threatens birds that rely on these habitats. This problem demands short-term solutions to address the habitat issues of the present while working to address longer-term solutions for reliable water supplies, even with the threat of climate change.

Working with partners, Audubon has advanced public policy initiatives, water efficiency measures, and market-based innovation to secure balanced water solutions for birds and people across the West. Recent successes include targeted restoration, timed releases of water for forest regeneration in the Colorado River Delta, and water management for open water and wetland creation at Owens Lake and Gillmor Sanctuary on Great Salt Lake. We need more positive steps to impact these habitats now. We must increase water supply resilience for both communities and birds in the West with policies that provide for sustainable use and conservation of this rich network of streams, rivers, wetlands, lakes, and estuaries. Because the current water supply is often inadequate for these habitats, we must also pursue strategies to augment habitat in some places, such as through cultivation of native vegetation and development of managed wetlands and backwaters.

This report synthesizes scientific linkages between water and birds in the arid West at a regional scale. It documents the changes that have taken place that threaten the ability of these critical habitats to support healthy populations of birds, focusing on two main geographies: riparian systems of the Colorado River Basin and a network of saline lakes in the Intermountain West. The report complements Audubon's work in the region, by describing key places and species, and establishing relationships between water, habitat, and birds.

EXECUTIVE SUMMARY

Overview

Water is the most precious resource in the West—for people, birds, and other wildlife. Riparian habitats like the forests and wetlands that line the Colorado River support some of the most abundant and diverse bird communities in the arid West, serving as home to some 400 species. The Colorado River also provides drinking water for more than 36 million people, irrigates 5.5 million acres of farms and ranches, and supports 16 million jobs throughout seven states—with an annual economic impact of $1.4 trillion. But dams, diversions, drought, and water demand are triggering declines in cottonwood-willow forests and other native river habitat. Saline lakes—landlocked salt water lakes fringed with wetlands found throughout the Intermountain West—are beacons for millions of birds crossing an otherwise arid landscape. However, these lakes are shrinking and in some cases nearly disappearing. In short, precipitous declines in western water quantity and quality are exacting a toll on health, prosperity, and quality of life for rural and urban communities, and putting birds and wildlife at jeopardy.

Water and Birds in the Arid West: Habitats in Decline represents the first comprehensive assessment of the complex and vital relationships that exist among birds, water, and climate change in the region. Our research focused on two of the most imperiled and irreplaceable western ecosystems: 1) the Colorado River Basin; and 2) the West's network of saline lakes— including the Great Salt Lake and Salton Sea as well as other smaller but vitally important lakes. Audubon science staff collaborated with outside experts in hydrology, water chemistry, and ecotoxicology, as well as ornithology, in an extensive review of the scientific literature on birds, water, and climate change in the region, with a particular focus on eight western states: Arizona, California, Colorado, New Mexico, Nevada, Oregon, Utah, and Wyoming. In addition, we synthesized regional bird data from a number of sources to assess impacts on birds in the region, and convened avian experts to deepen our shared understanding of the migratory movement of shorebirds and waterbirds among western saline lakes.

Research Objectives:

- Increase our understanding of how the decline of riparian habitat in the Colorado River Basin and at saline lakes is impacting birds
- Assess the status of key western bird species representative of multiple species that depend on riparian and saline lake habitat
- Analyze impacts and threats to these species' habitat posed by lack of available water and the anticipated effects of climate change
- Provide recommendations for water policy priorities and future research

Riparian Systems of the Colorado River Basin

Although riparian zones account for less than 5% of the southwestern landscape, they support over 40% of all bird species found in the region and over 50% of breeding bird species. These include at least 400 species along the lower Colorado River. If current western water trends continue and are compounded by climate change, many bird species face diminished and degraded habitat and an uncertain future.

Key findings:

- Native riparian trees and shrubs such as cottonwood-willow ecosystems that provide productive habitat for birds and other wildlife are disappearing as a result of water development—including damming, flow regulation, surface water diversion, and groundwater pumping.
- Hydrology changes have also spurred the spread of non-native plants, particularly saltcedar, throughout the Colorado River Basin—reducing biodiversity and the number and variety of birds in many riparian habitats.
- Populations of the following breeding birds, once common along the Colorado River, have experienced significant regional declines: Western Yellow-billed Cuckoo, Southwestern Willow Flycatcher, Bell's Vireo, Yellow Warbler, Yellow-breasted Chat, and Summer Tanager.

- Three species, Yuma Ridgway's Rail, Western Yellow-billed Cuckoo, and Southwestern Willow Flycatcher, are now listed as federally threatened or endangered, and at risk of extinction if current trends continue.
- Climate change is projected to exacerbate habitat declines across the basin, reducing water supply, raising temperatures and aridity, and disrupting phenology—the timing of seasonal natural phenomena such as spring floods, plant flowering, and insect hatching.

Saline Lakes and Wetlands of the Intermountain West

We focused our analysis on the nine western saline lakes with the greatest importance for birds. More than half of these have shrunk by 50 to 95% over the past 150 years. However, despite widespread awareness of the importance of water—and concern about adequate western water supply—much of the available research on saline lakes and birds was focused on individual lakes. By bringing these isolated studies together, we were able to better understand how birds "use" the widely dispersed lakes and wetlands as an interconnected network of habitats. No other linked ecosystems in the Intermountain West can meet these species' requirements—and because shorebirds and waterbirds congregate in large numbers at major lakes, they are particularly vulnerable to habitat loss.

Key findings:

- Collectively, saline lakes in the West support global populations of birds, including over 99% of the North American population of Eared Grebes, up to 90% of Wilson's Phalaropes, and over 50% of American Avocets.
- Saline lakes are critically important to migratory shorebird species, whose populations have declined nearly 70% since 1973.
- Water levels in saline lakes have declined dramatically in the last 100+ years due to draining, diversions of inflows, and lake and groundwater extraction.
- Lower water levels have increased lake salinity, altering food webs and reducing invertebrate food sources for migrating and resident shorebirds and waterbirds.
- Drier conditions under climate change will exacerbate the impacts of water diversion on saline lakes by decreasing freshwater inflows.

Recommendations

Approaches to western water that protect the needs of birds and wildlife as well as people are possible, but only if stakeholders align good outcomes for water-dependent habitats with solutions that decrease shortage risks for people. Ultimately, the challenge is to find sustainable ways for people and birds to use water and co-exist in the West. That is where Audubon—and this report—comes in. By providing a clear, credible assessment of the importance of sound western water management for birds and habitat, we can mobilize the Audubon network of members, chapters, and others who love birds around balanced water solutions. The following recommendations provide a springboard for conservation action; they also lay the foundation for further research and the development of innovative water management solutions.

- Identify and support balanced solutions and water policies at the local, state, and federal levels that avoid depleting water supplies for rivers, lakes, and wetlands and associated habitats
- Engage with water users, policy-makers and community leaders to collectively improve understanding of the importance of finding solutions that work for people and birds
- Train and mobilize the Audubon network on behalf of creative, sensible water solutions and policies
- Increase public and private investment in water conservation, habitat restoration, and research
- Secure voluntary water sharing agreements, including market-based solutions, and encourage flexible water management practices to improve water flows for habitats
- Leverage our science to develop and implement management plans that factor in habitat needs and restoration of native vegetation
- Foster greater dialogue and action to reduce global climate change and its impacts on water availability

- Advance scientific understanding of bird populations and habitat linkages across western landscapes through additional research, field study, and monitoring
- Use climate change and connectivity modeling to prioritize conservation and restoration

Conclusion

Water management practices that fail to take into account ecosystem health and the impacts of climate change are the greatest threats to birds that rely on the Colorado River Basin and western saline lakes. It is our hope that the findings and recommendations in this report will play a vital and much-needed role in shaping the future of water in the West. Decisions about water allocation and management are being made now: cities, states, and even countries are coming to the table to develop water solutions. The challenges we face on the Colorado River and across saline lakes are significant. However, this does not mean there is not enough water to go around. There is. We need a new phase of collaboration, innovation, and flexibility when it comes to how we use, share, and manage water, coupled with investments in water conservation, improved infrastructure, and habitat restoration. Solving these water management challenges will enable the people, birds, and wildlife of the arid West to thrive together.

STRATEGIC PRIORITIES

Across the vast geography of the West, water is the lifeblood for both birds and people. After analyzing threats and evaluating opportunities to make meaningful contributions to conservation, Audubon's Western Water Initiative focused on selected landscapes in the West where water scarcity and water quality are the limiting factors for the survival of threatened and iconic bird species.

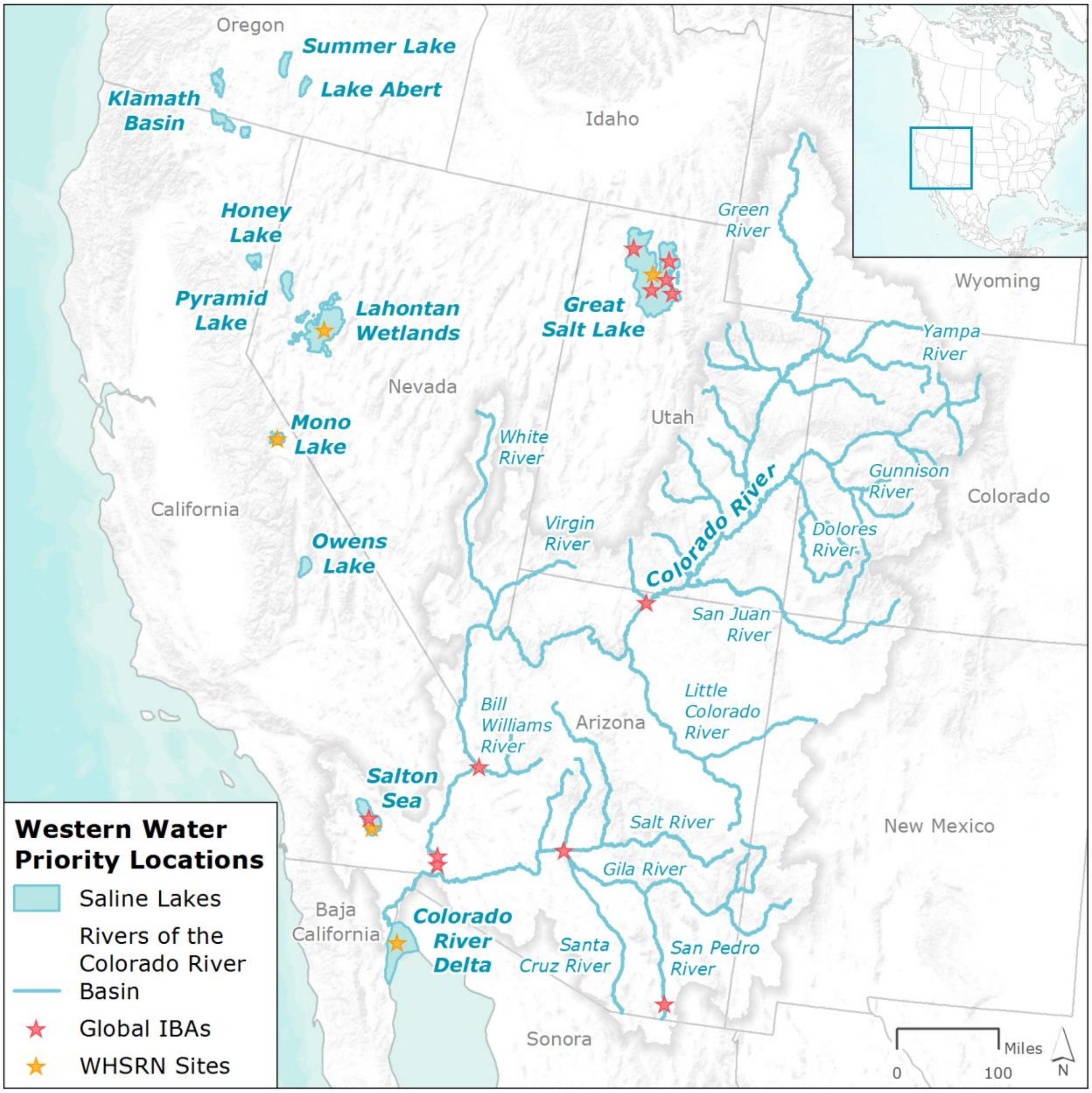

Figure 1. Priority geography of the Western Water Initiative, encompassing riparian systems of the Colorado River Basin and major saline lakes of the Intermountain West. Global Important Bird Areas (IBAs) and Western Hemisphere Shorebird Reserve Network (WHSRN) sites within this geography are also shown. The Colorado River Delta and Klamath Basin, although not saline lakes *per se*, are also included because they provide valuable habitat for waterbirds in this region. The Colorado River Delta and Salton Sea are included in both the Colorado River Basin and as saline lakes.

Table 1. Priority species of the Western Water Initiative (sorted taxonomically).

Colorado River Basin	Saline Lakes
Yuma Ridgway's Rail (*Rallus longirostris yumanensis*)	Ruddy Duck (*Oxyura jamaicensis*)
Lower Colorado River Valley Sandhill Crane (*Grus canadensis*)	Eared Grebe (*Podiceps nigricollis*)
Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*)	American White Pelican (*Pelecanus erythrorhynchos*)
Southwestern Willow Flycatcher (*Empidonax traillii extimus*)	White-faced Ibis (*Plegadis chihi*)
Bell's Vireo (*Vireo bellii*)	American Avocet (*Recurvirostra americana*)
Yellow Warbler (*Setophaga petechia*)	Western Snowy Plover (*Charadrius nivosus nivosus*)
Yellow-breasted Chat (*Icteria virens*)	Marbled Godwit (*Limosa fedoa*)
Summer Tanager (*Piranga rubra*)	Western Sandpiper (*Calidris mauri*)
	Wilson's Phalarope (*Phalaropus tricolor*)

Priority ecosystems (Figure 1) and bird species (Table 1) for the Western Water Initiative were developed with consideration of the analysis and identification of priorities by the North American Bird Conservation Initiative (NABCI) Committee, Bird Life International's Important Bird and Biodiversity Areas (IBAs) programs, Partners in Flight (PIF), Western Hemisphere Shorebird Reserve Network (WHSRN), Intermountain West Joint Venture, Sonoran Joint Venture, and other conservation collaboratives. All of these groups are in agreement: the rivers of the Colorado River Basin and saline lakes and their associated wetlands throughout the Intermountain West provide critical habitats for birds.

NABCI identified lowland streams and saline lakes in the West as priorities for conservation because they provide quality breeding, migratory, and winter habitat for birds and are at risk from water scarcity. The Colorado River Basin and Great Salt Lake were among NABCI's riparian, wetland, marsh, and saline lake habitat priorities. Riparian habitats are among the rarest of forest types in western North America, making up less than 5% of the total land mass (Krueper 2000). In the West, up to 95% of riparian habitats have been altered, degraded, or destroyed to the detriment of the species that depend on them (Krueper 2000). Saline lakes and associated wetland, playa, and mudflat habitats are diminishing as well due to a warming climate and competition over water for agriculture and urban consumption (Williams 2002). This is certainly true in the Intermountain West, where sites of high importance for breeding and non-breeding shorebirds are in jeopardy, including Lake Abert, Great Salt Lake, and Salton Sea (e.g., Shuford et al. 2004b, IMWJV 2013, Moore 2016).

A review of Global IBAs also highlighted the importance of the Colorado River Basin and saline lakes in the Intermountain West (Figure 1). IBAs are sites identified as globally important for the conservation of bird populations on the basis of globally standardized criteria identifying large aggregations of birds and/or significant populations of IUCN Red List species. In the U.S., sites are identified by the National Audubon Society, in partnership with BirdLife International. IBAs also form the core of the global network of Key Biodiversity Areas (KBAs), sites that are important for the global persistence of biodiversity. Global IBAs designated in the Colorado River Basin include the Bill Williams River National Wildlife Refuge IBA, Lower Salt and Gila Riparian Ecosystem IBA, San Pedro Riparian National Conservation Area IBA, Imperial Reservoir and National Wildlife Refuge IBA, and Delta of the Colorado River IBA. Additionally, all of the saline lake priority sites have been identified as State or Global IBAs, including five individually recognized Global IBAs at Great Salt Lake (Bear River Bay, Farmington Bay, Gilbert Bay, Gunnison Bay, and Ogden Bay).

The Great Salt Lake is the largest saline lake in the Western Hemisphere and the fourth largest in the world. The Intermountain West Regional Shorebird Plan of 2013 notes that Great Salt Lake stands out as "probably the most important inland shorebird site in North America, easily surpassing on single days the WHSRN Hemispheric Site requirement for 500,000 shorebirds annually"

(Oring et al. 2013). Other large saline lakes in the West that surpass the annual requirement of 100,000 shorebirds for status as a WHSRN International Site include the Salton Sea, Lake Abert, Summer Lake, Mono Lake, and Owens Lake. The Lahontan Valley of Nevada, a complex of saline playas and freshwater marshes, has been classified as a Hemispheric Site by WHSRN, surpassing the annual requirement of 100,000 shorebirds.

There are hundreds of bird species that breed, migrate through, or winter in either the Colorado River Basin or saline lakes in the West. In this report, Audubon has selected a subset of representative priority species. Nearly all species of western nongame migratory birds identified as conservation priorities by PIF have been recorded within riparian ecosystems.

The eight priority species for the Colorado River Basin (Table 1) are all riparian forest and wetland specialists within the region and many are of high conservation concern (Table 2). These species have all experienced historical declines or range contractions, and four are now protected at the state or federal level. The future of these species is tied to the river.

Nine priority species were selected to be featured in this report that capture the breadth of habitats used by birds in saline lakes and their associated wetlands, mudflats, and playas (Table 1). The recently released Pacific Americas Shorebird Conservation Strategy documents that "shorebirds are especially vulnerable to environmental and anthropogenic perturbations and as a group are not faring well" (Senner et al. 2016). In the Pacific Americas Flyway, 11% of shorebird populations demonstrate long-term declines, while another 46% have unknown population trends. Other waterbirds have low conservation concern but are highly dependent on saline lake habitats, including Eared Grebes, millions of which congregate at saline lakes in the fall.

These priority landscapes and species are of strategic value, but they are not exhaustive. This report does not summarize the status and threats to riparian systems outside of the Colorado River Basin, even though these habitats exist elsewhere in all of the eight states we researched. Similarly, this report does not summarize the status and threats to all saline lakes in the West, or to the coastal and agricultural habitats used by shorebirds and waterbirds. However, many of the threats, impacts, knowledge gaps and future strategies outlined in this report for the Colorado River Basin and saline lakes of the Intermountain West are relevant throughout the western U.S.

Over the next five years, Audubon's Western Water Initiative will focus on major waterbodies in the Central and Pacific Flyways, including rivers of the Colorado River Basin, the Colorado River Delta, and saline lakes of the Intermountain West, such as the Great Salt Lake and Salton Sea. The next several years present an extraordinary opportunity for Audubon and its partners to envision and implement new ways to use a finite supply of water to secure habitat necessary for birds and wildlife, as well as people, for many years to come.


Colorado River by Denny Armstrong / Flickr CC (BY 2.0)

RIPARIAN SYSTEMS OF THE COLORADO RIVER BASIN

Overview and Importance

The Colorado River is one of the largest rivers in the U.S., flowing nearly 1,500 miles and draining a basin that encompasses 244,000 square miles in parts of seven U.S. and two Mexican states (Kammerer 1987). The rivers of the Colorado River Basin are formed by a vast network of headwater creeks, arising in the Rocky Mountains at elevations as high as 14,000 feet above sea level, that drain into major tributaries, including the Green, Yampa, White, Little Snake, Gunnison, Dolores, San Juan, Little Colorado, Bill Williams, and Gila Rivers. In all, these rivers comprise more than 273,000 miles of river habitat fanned out across this otherwise arid region. At the southern end of the watershed, this entire network of rivers drains into the upper Gulf of California (also known as the Sea of Cortez); the Colorado River Delta is a rare freshwater habitat in the midst of the Sonoran Desert.

Located along streambanks, riparian habitats form where the water table is sufficiently high to support large trees and shrubs and overbank flooding creates conditions that support germination of seedlings. Riparian habitats in the Colorado River Basin are diverse and productive ecosystems supporting dense growths of vegetation and a diverse bird community (RHJV 2004). Although riparian zones account for less than 5% of the landscape (Krueper 2000), they support over 40% of all bird species found in the Southwest (Hunter et al. 1988) and over 50% of the breeding bird species (Johnson et al. 1977), including at least 400 unique species along the lower Colorado River (Ohmart et al. 1988). Avian presence in riparian habitats shifts seasonally, as birds move through different parts of their life cycle, and resources change with the seasons (Rice et al. 1983, Stromberg et al. 2012). Millions of Neotropical migrants use riparian zones as stopover habitat, reaching densities over 10 times greater than found in the surrounding landscape (Carlisle et al. 2009, Fischer et al. 2015), and a number of insect and seed-eating birds winter in these habitats (Anderson et al. 1983).

Cottonwood-willow forests, in particular, are some of the most abundant and diverse avian habitats due in large part to their structural complexity, which offers a variety of food resources, nesting sites, and shelter (Ohmart et al. 1988, Brand et al. 2008). Reaching heights up to 90 feet, cottonwoods are often the tallest trees on the landscape (Webb et al. 2007). Multiple layers of vegetation provide nesting sites for both midstory-nesters like Bell's Vireo and Yellow-breasted Chat, and canopy-nesters like Summer Tanager, which are often absent from shrubby habitats (Brand et al. 2010). Abundant cicadas and other insects provide more than enough food to support multiple species (Rosenberg et al. 1982). A canopy of leaves provide shade in the intense heat.

Open water, along the river channel and in oxbows and backwater ponds, also provides critical habitat for birds in the Colorado River Basin (Hinojosa-Huerta 2006). Surface water is essential for breeding insects that comprise an important food source for riparian birds (Iwata et al. 2003). In addition, backwater ponds support marsh ecosystems that are otherwise rare in the arid landscape of the Colorado River Basin. The Yuma Ridgway's Rail, for example, is endemic to the lower Colorado River Basin and requires these marsh habitats (Anderson 1983, Hinojosa-Huerta 2000).

River dynamics that create and sustain habitat

Historical flows on the Colorado River were highly variable, moved large amounts of sediment, and recharged large aquifers (Webb and Leake 2006). The river's annual yield ranged from 4-24 million acre-feet, and the paleo record indicates even greater variation (USBR 2012). There was also a decadal trend driven by Pacific Ocean temperatures, with alternating wet and dry periods (USBR 2012). Flows varied widely within the year due to snowmelt runoff and summer monsoon events. The riparian forests evolved along with this regime. Variable flows led to the formation of wide valleys and terraces along the river that supported cottonwood-willow forests on the lower banks, sustained by high groundwater and frequent floods, and mesquite on the higher, more stable banks (Ohmart et al. 1988, Webb and Leake 2006). With riparian vegetation largely dependent on river flows, its extent has also varied over time (Baron et al. 2003).

Cottonwood-willow forests are uniquely adapted to the natural hydrology of the Colorado River Basin, requiring high groundwater levels for their persistence and periodic floods for their regeneration (Ohmart et al. 1988, Graf et al. 2002, Webb and Leake 2006, Merritt and Bateman 2012, Stromberg et al. 2012, Hinojosa-Huerta et al. 2013). Mature cottonwood-willow forests grow at elevations below 6,000 feet in valley bottoms where groundwater is less than 9 feet below the floodplain surface (Stromberg et al. 1996, Stromberg 1998, Andersen et al. 2007), but regeneration requires groundwater less than 3 feet down (Stromberg et al. 1996). Surface flows are required to maintain shallow water tables (Merritt and Bateman 2012) and germinate seedlings that have not yet established roots to access groundwater (Shafroth et al. 1998, Hinojosa-Huerta et al. 2013). Seedling desiccation in the dry season limits the extent of tree cover (Mahoney and Rood 1998, Stella et al. 2010). Although cottonwoods and willows are resilient to low flows and short-term droughts (Hinojosa-Huerta et al. 2013), they are highly sensitive to fluctuations in groundwater levels, and groundwater pumping can kill these plants in a matter of days (Stromberg et al. 1996, Graf et al. 2002, Webb and Leake 2006).

Floods are the primary natural disturbance in southwestern riparian ecosystems (Nilsson and Svedmark 2002). While floods often result in the immediate loss of vegetation, they create conditions necessary for the regeneration of native vegetation by moistening soils, recharging groundwater, flushing salts, scouring vegetation, and depositing sediments, nutrients, and seeds (Graf et al. 2002, Merritt and Bateman 2012). The synchronous timing of seed dispersal and peak flows in spring and early summer is critical for regeneration, as short-lived seeds require moist, bare sites to grow (Shafroth et al. 1998, Karrenberg et al. 2002, Merritt and Poff 2010, Stromberg et al. 2012). Seedling recruitment is dependent on floods that create these conditions, and an appropriate river flow recession that enables growing roots to maintain contact with an adequate amount of soil moisture (Mahoney and Rood 1998, Stella et al. 2010). Changes in the magnitude, frequency, and timing of floods can have devastating effects on the native riparian community, causing mortality of native trees and preventing regeneration of seedlings (Merritt and Poff 2010).

Status of Priority Species

We identified eight riparian birds of conservation concern in the Colorado River Basin: Yuma Ridgway's Rail, Sandhill Crane, Western Yellow-billed Cuckoo, Southwestern Willow Flycatcher, Bell's Vireo, Yellow Warbler, Yellow-breasted Chat, and Summer Tanager (Table 2). All are riparian specialists in this portion of their range. The declines of Yuma Ridgway's Rail, Western Yellow-billed Cuckoo, and Southwestern Willow Flycatcher have led to their federal listing under the

Endangered Species Act (USFWS 1967, USFWS 1995, USFWS 2014a), and Bell's Vireo is state listed in California (Arizona subspecies) and New Mexico (Poole 2005). Additionally, breeding populations of Summer Tanager, Yellow-breasted Chat, and Yellow Warbler have all showed historical declines in the region (Ohmart et al. 1988), and the Lower Colorado River Sandhill Crane population has experienced winter range contractions (Kruse et al. 2014). The best present-day estimates of regional population trends are based on the North American Breeding Bird Survey (BBS), a roadside survey that is not designed specifically for riparian birds and does not sample riparian areas systematically across the region. Area-weighted state population trends from BBS suggest that populations of most priority riparian birds have increased in the Colorado River Basin since the mid-1960s, except Western Yellow-billed Cuckoo and Southwestern Willow Flycatcher (Table 2, Sauer et al. 2017). Population estimates for Arizona and the portion of the lower Colorado River including Arizona, California, and Nevada are the only regional estimates available based on a uniform sampling protocol (Table 2). These estimates indicate that further habitat loss could also threaten populations of Summer Tanager and Sandhill Crane due to small population sizes in the region.

Table 2. Colorado River Basin priority species, description of preferred habitat, conservation status, global population estimate, abundance estimate within the basin, and population trend within the basin.

Priority Species	Preferred Habitat[1]	Conservation Status[1]	Total Population Estimate	Colorado River Basin Abundance Estimate	Basin Population Trend[2]
Yuma Ridgway's Rail[3] (year-round)	Salt and brackish marshes dominated by cordgrass, pickleweed, or mangroves.	Listed as federally endangered in 1967. State endangered in California and Arizona. Threatened by loss and degradation of wetland habitat.	8,380	8,380	Stable
Lower Colorado River Valley Sandhill Crane[4] (wintering)	Shallow wetlands, playa lakes, and sandbars along shallow rivers. Wintering areas are often closely associated with grain fields.	Lower Colorado River Valley population is small but stable.	3,353	3,353	Stable (1.03)
Western Yellow-billed Cuckoo[5] (breeding)	Riparian forests with tall canopies (90 feet) comprised of willow, cottonwood, alder, walnut, and mesquite. Nest in willows and forage in cottonwoods. Prefer large and wide riparian patches (>200 acres and at least 0.5 miles wide).	Listed as federally threatened in 2014. State endangered in California. Identified as a species of concern in Arizona, Montana, Colorado, and Texas; state-sensitive species in Utah; species of greatest conservation need in Idaho, New Mexico, and Wyoming; and critically imperiled in Nevada.	1,750	398	Decreasing (-2.27)
Southwestern Willow Flycatcher[6] (breeding)	Shrubby riparian forests with standing or running water and a dense understory.	Listed as federally endangered in 1995.	1,299 territories	823 territories	Decreasing (-1.18)

Priority Species	Preferred Habitat[1]	Conservation Status[1]	Total Population Estimate	Colorado River Basin Abundance Estimate	Basin Population Trend[2]
Bell's Vireo[7] (breeding)	Riparian habitats with dense, low shrubs or small trees for habitat and nest building, including willow, mesquite, and saltcedar. Surface water is important in arid regions.	Least subspecies listed as federally endangered in 1986 and occurs mostly outside of the Colorado River Basin. Least and Arizona subspecies state endangered in California. State threatened in New Mexico. Multiple subspecies listed by Partners in Flight as Bird of Conservation Concern.	4,600,000	88,359	Increasing (1.17)
Yellow Warbler[7] (breeding)	Wet riparian forests dominated by willows. Found at elevations between 300 and 9,000 feet in California and Arizona, and at higher elevations along rivers with riparian vegetation.	Western populations affected by loss of riparian habitat.	90,000,000	104,162	Increasing (1.39)
Yellow-breasted Chat[7] (breeding)	Dense riparian forests dominated by mesquite, cottonwood-willow, or saltcedar. Prefer habitat with an open overstory and dense understory. Generalist in nesting habitat.	Not federally listed, but state listed or considered a species of concern on the northern boundaries of its range.	13,000,000	83,624	Increasing (1.69)
Summer Tanager[7] (breeding)	Riparian forests dominated by cottonwoods and willows at lower elevations; mesquite and saltcedar habitats at higher elevations. Prefer broad riparian zones.	Populations declining in the lower Colorado River valley due to loss of riparian habitat.	12,000,000	33,430	Increasing (1.67)

[1] Habitat descriptions and conservation status are from Birds of North America Online species accounts (Poole 2005).

[2] Basin population trends for breeding species were calculated by area-weighting BBS trends (1966-2015, Sauer et al. 2017) for the basin states (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) based on the proportion of the state within the Colorado River Basin.

[3] Total population estimates, Colorado River Basin abundance estimates, and population trend for Yuma Ridgway's Rail are from the Waterbird Population database (Wetlands International 2017).

[4] Total population estimates, Colorado River Basin abundance estimates, and population trend (1998-2007) for Lower Colorado River Valley Sandhill Crane are from Kruse et al. (2014).

[5] Total population estimates for Western Yellow-billed Cuckoo are from the U.S. Fish and Wildlife Service (USFWS 2014b). Colorado River Basin abundance estimates were calculated by summing counts from the Lower Colorado River Multi-species Conservation Program (McNeil et al. 2013), Colorado River Delta (O. Hinojosa-Huerta, pers. comm.), Arizona Game and Fish Department (Corman et al. 2017), and surveys in the Gila Valley of New Mexico (Shook 2016). Estimates reported as number of territories, breeding pairs, or detections were doubled to get numbers of individuals. These estimates are limited and do not consider other regions of the Colorado River Basin.

[6] Total population estimates and Colorado River Basin abundance estimates for Southwestern Willow Flycatcher are from Durst et al. (2008).

[7] Total population estimates for Bell's Vireo, Yellow Warbler, Yellow-breasted Chat, and Summer Tanager are from the Populations in Flight database (PIF 2013). Colorado River Basin abundance estimates were calculated by summing counts from the Lower Colorado River Multi-species

Conservation Program (GBBO 2015), Colorado River Delta (O. Hinojosa-Huerta, pers. comm.), and Arizona Game and Fish Department (Corman et al. 2017). Estimates reported as number of territories or breeding pairs were doubled to get numbers of individuals. These estimates are limited and do not consider other regions of the Colorado River Basin.

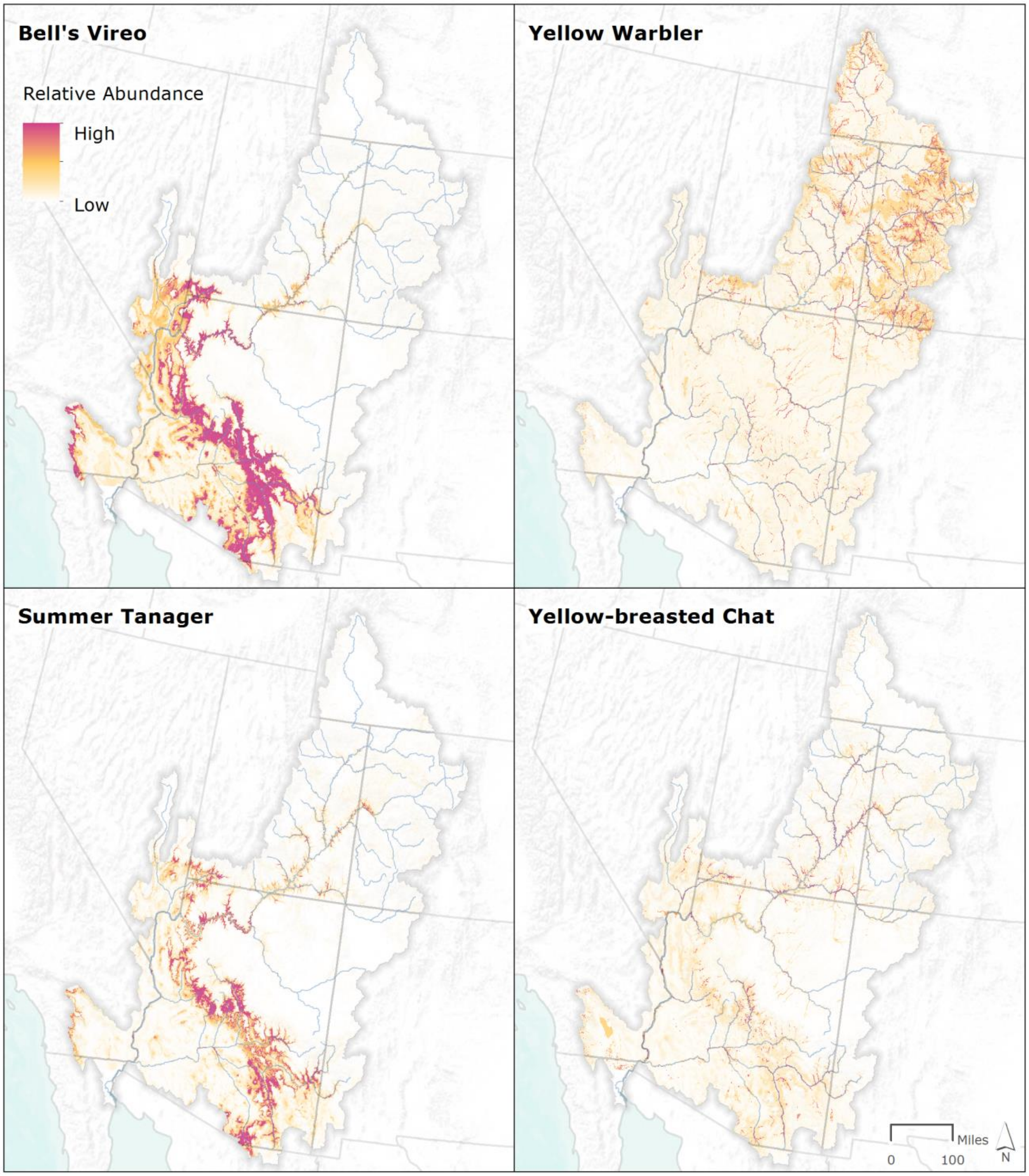

Figure 2. Modeled relative abundance of priority breeding species across the Colorado River Basin (excluding Mexico) using both eBird and North American Breeding Bird Survey observations as measures of abundance and a suite of environmental covariates encompassing land cover, landscape pattern, and terrain as covariates. See Appendix A for detailed methods.

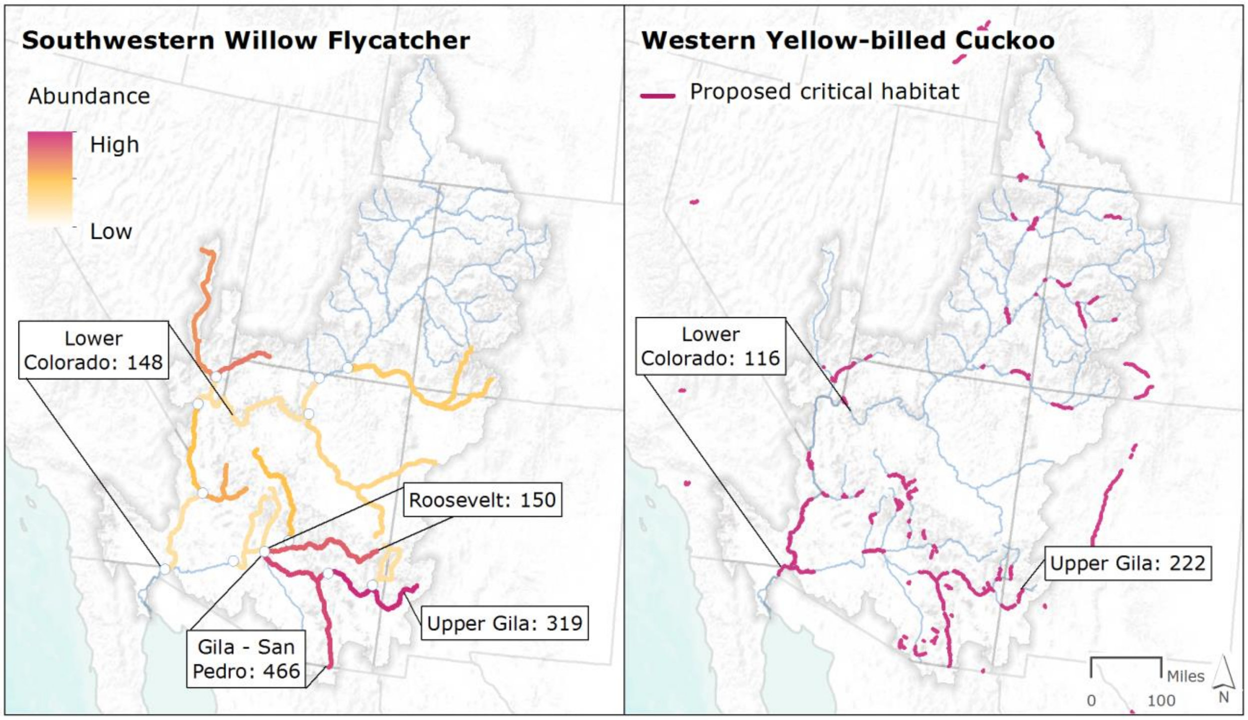

Figure 3. Southwestern Willow Flycatcher abundance (Durst et al. 2008) and Western Yellow-billed Cuckoo proposed critical habitat (USFWS 2015) in the Colorado River Basin. Call-out boxes give abundance estimates for Southwestern Willow Flycatcher along the lower Colorado River (McLeod and Pellegrini 2015), upper Gila River (Shook 2015), Roosevelt Management Unit (Durst et al. 2008), and Gila-San Pedro Management Unit (Durst et al. 2008), and for Western Yellow-billed Cuckoo along the lower Colorado River (McNeil et al. 2013), upper Gila River (Shook 2016), and Colorado River Delta (O. Hinojosa-Huerta, pers. comm.). Estimates reported as number of territories, breeding pairs, or detections were doubled to get numbers of individuals.

Priority species are most abundant along riparian corridors of the Colorado River Basin. The majority of Yuma Ridgway's Rails are concentrated in the Ciénega de Santa Clara at the Colorado River Delta, which supports about 6,000 individuals (Hinojosa-Huerta et al. 2008), over two-thirds of the total population. Four wintering sites in the lower basin support over 90% of the Lower Colorado River Sandhill Crane population: Cibola National Wildlife Refuge, Colorado River Indian Tribe lands, the Gila River, and Salton Sea (Kruse et al. 2014). Modeled relative abundance for a suite of four riparian specialists suggests that sub-basins differ in importance across the basin for Bell's Vireo, Yellow Warbler, Yellow-breasted Chat and Summer Tanager (Figure 2). Relative abundance was estimated using a combination of eBird and BBS observations (eBird Basic Dataset 2016, Pardieck et al. 2017, see Appendix A for detailed methods). Bell's Vireo and Summer Tanager are found throughout riparian corridors at lower elevations in Arizona, whereas both are found primarily on the mainstem Colorado River in Utah. Yellow Warbler and Yellow-breasted Chat are found throughout the basin. The highest abundances of Southwestern Willow Flycatcher occur along the Gila River and its tributaries in Arizona and New Mexico and along the White and Virgin Rivers in Nevada, Arizona, and Utah (Figure 3). Critical habitat for Western Yellow-billed Cuckoo occurs primarily at lower elevations along the lower Colorado River and Gila River and tributaries, and secondarily along rivers in the upper basin (Figure 3).

Threats

Two modern trends are changing Colorado River flows. First, a growing human population in the region has led to extensive use of Colorado River Basin water, to the point that spring floods are greatly diminished in many reaches and the river no longer flows all the way to its mouth in the upper Gulf of California (USBR 2012). Second, climate change is projected to decrease river flows considerably through the twenty-first century

(USBR 2012, Udall and Overpeck 2017). Together, these trends superimposed on historic (and pre-historic) variability suggest that demand for water combined with warmer temperatures and drought will strain the capacity of the river system to deliver water for natural systems and human use (USBR 2012). The experience of the lower Colorado River serves as a case study for the potential consequences of water development on natural systems (Figure 4). There, dams and water management have reduced peak flows, leading to losses of cottonwood-willow forest and expansion of invasive saltcedar (also known as tamarisk, *Tamarix* sp.). Ultimately, these changes have resulted in the listing of three bird species under the Endangered Species Act. While this is only one portion of the Colorado River Basin, the experience is common throughout the rivers of the basin. The pattern of declining peak flows is replicated even at the headwaters (Figure 4).

Water development

Today, the Colorado River is one of the most highly regulated waterways in the world. To provide drinking water for more than 36 million people and irrigate over 5 million acres of land, scores of dams, reservoirs, and canals have been built across the basin, with the potential to store 60 million acre-feet of water, or approximately four years of the historic average natural flows (USBR 2012). The majority of this storage capacity is behind the two largest of 15 major dams on the Colorado mainstem, but hundreds of smaller dams and diversions alter river flow throughout the basin. Water development has substantially altered the natural flow regime of the basin's rivers, as regulated releases from dams eliminate the natural flood cycle, decrease downstream discharge and groundwater recharge, reduce the extent of the active floodplain, and restrict channel formation (Nilsson and Berggren 2000). These changes have led to declines in surface water along the river channel, in backwaters, and oxbows (Figure 5), and to declines in native riparian vegetation along riverbanks. Hydrologic changes are the principal cause of the decline of native riparian ecosystems in the Colorado River Basin (Springer et al. 1999, Webb and Leake 2006, Merritt and Poff 2010). Freshwater marshes have also been lost throughout the basin due to groundwater drawdown and channel narrowing with flow regulation (Webb and Leake 2006, Weisberg et al. 2013).

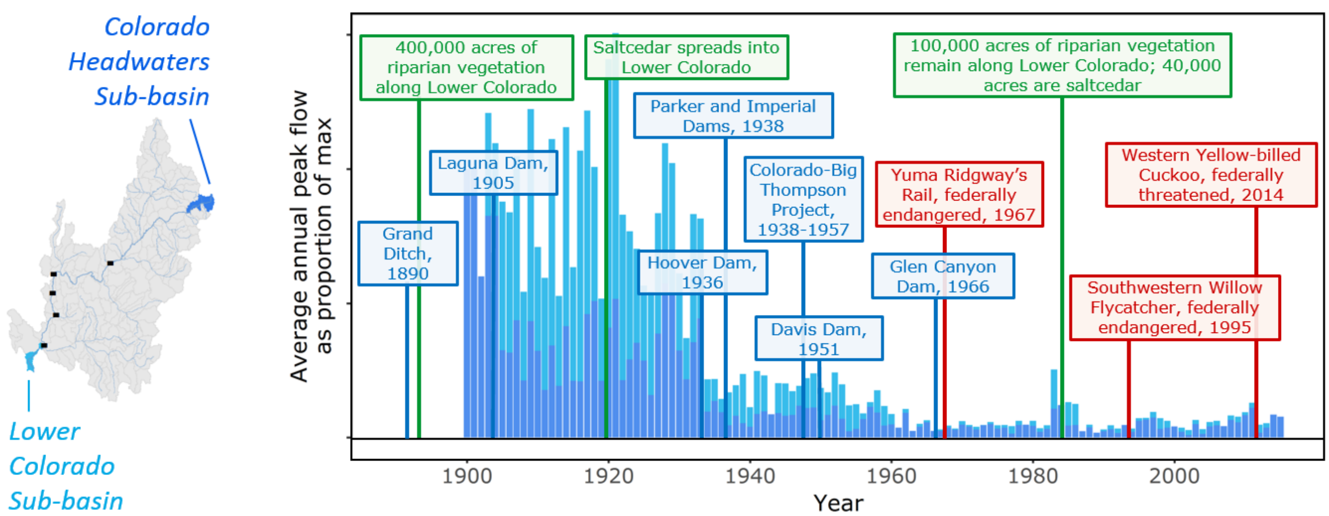

Figure 4. Time-series of average annual peak flows in the Lower Colorado River and Colorado Headwaters sub-basins over the past century. Both sub-basins show a sharp decline in the magnitude and variability of peak flows over the past century, concurrent with increasing hydrologic modifications within the Colorado River Basin. Text boxes depict construction of major dams (blue), notable changes in vegetation (green, Ohmart et al. 1988), and federal listing of threatened and endangered species (red) that relate to the lower Colorado River as a case study of change. Locations of sub-basins and major dams are shown on the map. Peak flow data are from the National Water Information System (USGS 2016b).

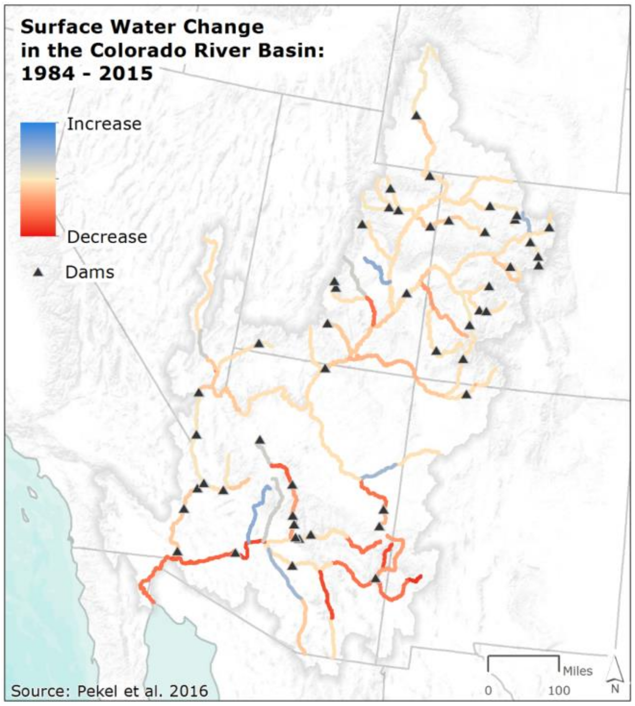

Figure 5. Change in the occurrence of surface water in the Colorado River Basin from 1984 to 2015 (Pekel et al. 2016). Average change in the occurrence of water assessed at a 30-m resolution is averaged within 1 kilometer of each river segment. A decline in the occurrence of surface water since the 1980s is visible, particularly in the tributaries of the Gila River in southern Arizona and the lower Colorado River in Mexico.

Loss of native trees and shrubs

Water impoundments, clearing for agriculture and urban development, river channelization, groundwater pumping, livestock grazing, timber harvest, and the spread of non-native species have all contributed to losses of native riparian vegetation across the West (Krueper 1993). In general, losses have occurred along regulated rivers downstream of dams, where diverted surface flows, excessive groundwater drawdown, and altered flood cycles no longer support native species (Webb and Leake 2006, Stromberg et al. 2010). Lowered groundwater levels and the desynchronization of peak flows and seed dispersal has caused mortality of native trees and prevented regeneration of seedlings (Stromberg et al. 1996, Webb and Leake 2006, Merritt and Poff 2010). Native vegetation has been eliminated along the Santa Cruz and Gila Rivers and declined along stretches of the Salt and Colorado Rivers in Arizona (Figure 6, Webb and Leake 2006). Losses in central Arizona, including along the Santa Cruz, Gila, and Salt Rivers, are primarily due to groundwater drawdown (Webb and Leake 2006). Declines in cottonwood-willow forests have been particularly severe (Ohmart et al. 1988, Snyder and Miller 1992, Andersen et al. 2007). In the upper Colorado River Basin, native cottonwood forests declined by 17.5% between 1951 and 1980, with an estimated loss of over 8 forest acres per river mile, mostly due to urban development and road construction (Snyder and Miller 1992). Remaining stands in the upper basin are thin and open, with the majority having less than 5% canopy cover, indicating they are comprised of older trees now disconnected from the river (Snyder and Miller 1992, Andersen et al. 2007). These forests will likely be completely eliminated once the older trees die and are not replaced, due to low recruitment of younger trees resulting from flow regulation (Andersen et al. 2007). Along the lower Colorado River downstream of Hoover Dam, there were approximately 400,000 acres of riparian vegetation in the late 1800s, but by the 1980s only 100,000 acres remained, and less than 1% of the remaining vegetation was mature cottonwood-willow forest (Ohmart et al. 1988). Currently, the Lower Colorado River Multi-Species Conservation Program (LCRMSCP), led by the Bureau of Reclamation to balance water use of the Colorado River with conservation of native species and their habitats, aims to restore 5,940 acres of cottonwood-willow forest (LCRMSCP 2004). This acreage was identified as the minimum required habitat extent required to support viable populations of threatened and endangered species.

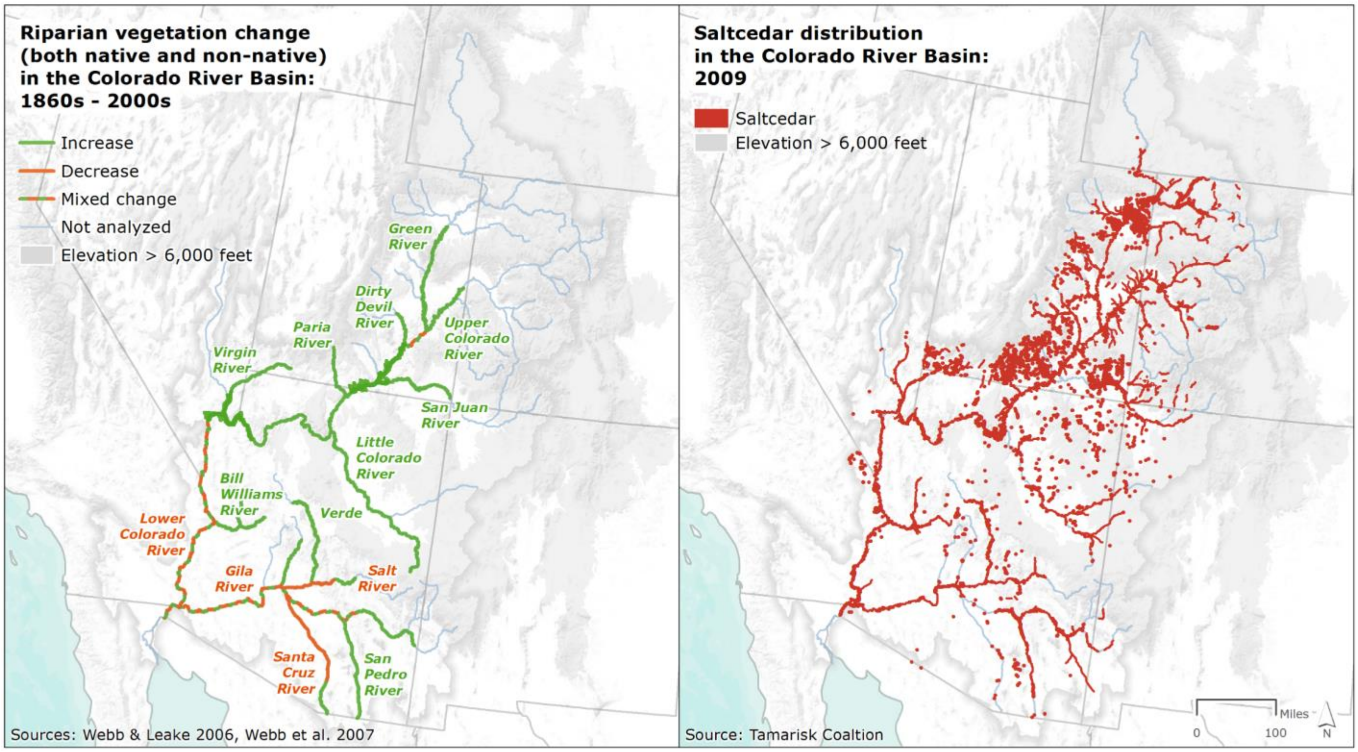

Figure 6. Riparian vegetation change from the 1860s to the early 2000s (left, adapted from Webb and Leake 2006, Webb et al. 2007) and distribution of saltcedar circa 2009 in the Colorado River Basin (right, Tamarisk Coalition 2009).

In some areas, riparian vegetation has increased in extent, sometimes through new establishment of cottonwood-willow forest, but mostly through the spread of non-native saltcedar (Figure 6, Webb and Leake 2006). A series of flows suitable for riparian tree establishment along the San Pedro River in the 1960s led to increases in woody riparian vegetation from 25% in 1955 to 62% in 2003, including a nearly three-fold increase in cottonwood-willow forests (Stromberg 1998, Webb and Leake 2006). Dams and flow regulation can result in reduced flood scour, enabling cottonwoods to grow in previously unstable areas of the floodplain if water tables remain high (Webb and Leake 2006, Stromberg et al. 2010). Since the completion of Alamo Dam in 1968 along the Bill Williams River in Arizona, there has been a >50% increase in the extent of riparian vegetation to over 1,200 acres in the 1990s due to more stable groundwater levels and increased seedling density and survival (Shafroth et al. 2002). Vegetation has also established along reservoir shorelines and deltas (Webb and Leake 2006), such as the forests along Roosevelt Lake in Arizona, which now support one of the largest Southwestern Willow Flycatcher breeding populations (Paxton et al. 2007).

Non-native shrubs

Many hydrologic changes have favored the spread of non-native species over natives. Saltcedar is a plant from Europe and Asia that was introduced to western North America over 100 years ago to control erosion, stabilize streambanks, create windbreaks, and serve as an ornamental (Jarnevich et al. 2011). Due to its deep roots, high water efficiency, opportunistic reproduction, and tolerance for high salinity, saltcedar has spread rapidly since its introduction, covering less than 1,000 acres in the 1920s to over 1,000,000 acres by the 1980s, expanding most rapidly between the 1940s and the 1960s, when major dam construction in the Southwest created conditions that displaced natives and allowed this species to establish (Jarnevich et al. 2011, Nagler et al. 2011). Other non-native plants of concern in the basin include Russian olive (*Elaeagnus angustifolia*, Katz and Shafroth 2003), tree of heaven (*Ailanthus* sp.), and giant reed (*Arundo donax*, USDA NRCS 2017). None of these non-native plants provide habitat for birds equivalent in quality to native vegetation.

Table 3. A comparison of the key traits that have facilitated the spread of saltcedar and the decline of cottonwood-willow forests.

Trait	Cottonwood-willow Forests	Saltcedar	Hydrologic change
Rooting depth	9 feet	30 feet	Declining groundwater levels
Seed dispersal window	February to June	March to October	Shifts in the timing of peak flows
Salinity tolerance	5 g/L	35 g/L	Reduced frequency of flooding

Because the spread of saltcedar has occurred concurrently with the loss of cottonwood-willow forests, saltcedar is often misjudged as the major cause of these declines, rather than as another symptom of hydrologic change (Stromberg et al. 2009, Merritt and Poff 2010). Although capable of tolerating a wide range of conditions (Table 3), saltcedar is outcompeted by cottonwoods and willows along river reaches that have maintained natural flows (Stromberg et al. 2009, Merritt and Poff 2010). Saltcedar has spread into modified sites that no longer support native cottonwood-willow forests, replacing, but not displacing, these species (Stromberg et al. 2007, Nagler et al. 2011). On the Gila and lower Colorado River in Arizona, cottonwood-willow forests dominated reaches with natural flood regimes and perennial flows, while saltcedar accounted for less than 10% of the vegetation in these systems (Stromberg et al. 2007). Instead, saltcedar dominated reaches with regulated and intermittent flows. In another comparative study, saltcedar was more abundant along the regulated Bill Williams River than along the unregulated Santa Maria and persisted in areas where low water levels had killed cottonwoods and willows (Shafroth et al. 1998, Shafroth et al. 2002). In the Colorado River Delta, low flows and regional drought in the early 2000s caused native tree cover to be reduced by half, dropping from 8% to 4%, while saltcedar cover almost doubled, increasing from 15% to 26% between 2002 and 2007 (Hinojosa-Huerta et al. 2013). Along the unregulated San Pedro River, saltcedar dominates dry sites in the middle basin where water levels are low, but is scarce in the upper basin where year-round flows support cottonwood-willow forests (Stromberg 1998).

Impacts on Birds

Birds thrive where native vegetation and perennial surface water are present (Brand et al. 2010). Non-native vegetation near surface water also support birds; but with lower species diversity and reduced reproduction for some vulnerable species. When water becomes scarce, the value of riparian habitats for birds is vastly diminished (Figure 7). Evidence from the recent past demonstrates how avian communities have suffered through the loss of native habitat, but have also made use of saltcedar-dominated habitat under certain conditions.

Concurrent with the loss of native cottonwood-willow forests, at least six breeding birds that were once common along the Colorado River decreased considerably in abundance, including Bell's Vireo, Summer Tanager, Southwestern Willow Flycatcher, Western Yellow-billed Cuckoo, Yellow-breasted Chat, and Yellow Warbler (Rosenberg et al. 1982, Hunter et al. 1988, Ohmart et al. 1988, Paxton et al. 2007). Within just 10 years along the lower Colorado River, Western Yellow-billed Cuckoo declined by an estimated 42%, from 450 individuals in 1976 to 261 individuals in 1986; Bell's Vireo declined by an estimated 57%, from 203 individuals in 1976 to 88 individuals in 1986; and Yellow-breasted Chat declined by an estimated 30%, from 997 individuals in 1976 to 700 individuals in 1986 (Ohmart et al. 1988). The precipitous decline of the Southwestern Willow Flycatcher to less than 1,000 individuals led to its listing as federally endangered in 1995 (USFWS 1995). Similarly, the Western Yellow-billed Cuckoo was recently listed as federally threatened in 2014, following population declines and range contractions (USFWS 2014a).

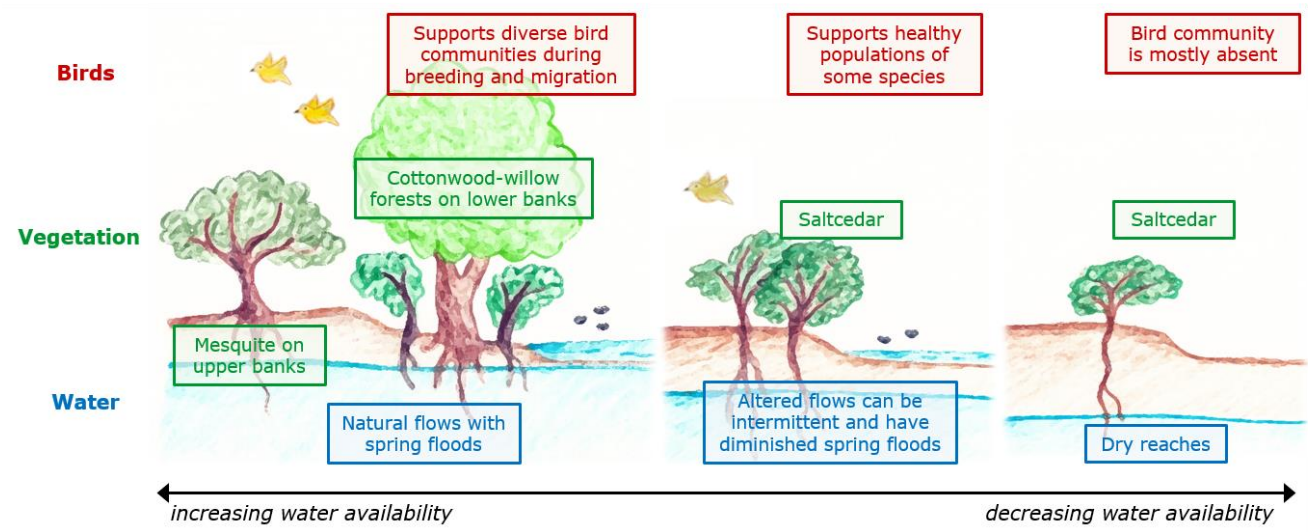

Figure 7. Typical habitat transitions with decreasing water availability in the Colorado River Basin.

Remaining patches of native vegetation continue to provide high-quality habitat for birds. Along the San Pedro River, densities of canopy-nesting birds were over 2.5 times greater in cottonwood-willow forests compared to saltcedar-dominated habitat, and were over 5 times greater for water-obligate birds (Brand et al. 2010). Furthermore, the number of fledglings per year for a shrub-nesting species like Bell's Vireo was significantly higher in native cottonwood-willow habitat than saltcedar (Brand and Noon 2011). Other native shrubs are also important. Along the lower Colorado River in Arizona, the timing of spring migration is synchronized with the flowering of honey mesquite (McGrath et al. 2009). Migrants selected honey mesquite as stopover sites over cottonwood, willow, and saltcedar, and reached their highest abundance in these habitats as flowering peaked, likely due to the high biomass of insects attracted to these flowers (McGrath et al. 2009).

Birds have shown some behavioral plasticity and colonized saltcedar-dominated habitats, which show their greatest value when in close proximity to native cottonwood-willow forests (van Riper et al. 2008) or where there otherwise would have been no vegetation (Hunter et al. 1988, Skagen et al. 1998, Sogge et al. 2008). At least 49 bird species have been observed breeding in saltcedar in the Southwest (Sogge et al. 2008), including species of concern, like Southwestern Willow Flycatcher (Durst et al. 2006) and Western Yellow-billed Cuckoo (Sechrist et al. 2013). Roughly half of the known Southwestern Willow Flycatcher breeding territories are in habitats where saltcedar accounts for a substantial proportion of the vegetation (Durst et al. 2006), and no differences in productivity, juvenile survivorship, or body condition have been found in these habitats (Owen et al. 2005, Paxton et al. 2007). Along the San Pedro River, saltcedar supports high densities of mid-story nesters (e.g., Bell's Vireo and Yellow-breasted Chat) in the breeding season (Brand et al. 2011), but Bell's Vireo nests produce fewer fledglings (Brand and Noon 2011). Saltcedar also supports insectivores during migration (Cerasale and Guglielmo 2010). Along the lower Colorado River, many birds reached their highest abundance in mixed habitats where saltcedar accounted for 40-60% of the vegetation (van Riper et al. 2008). Saltcedar might increase riparian habitat for birds by providing additional structural diversity, greater foliage volume, and supplementary food sources, but these positive aspects are maximized in the presence of native vegetation (van Riper et al. 2008, Villarreal et al. 2014). With the release of the saltcedar leaf beetle in 2001, there are now concerns that removal of saltcedar will result in a net decline in riparian habitat for birds, considering that high-quality native habitat is unlikely to develop where saltcedar occurs (Sogge et al. 2008, Bloodworth et al. 2016).

Declines in water availability may be a bigger threat to riparian birds than changes in vegetation composition (Hinojosa-Huerta 2006). Southwestern Willow

Flycatchers typically nest streamside, and evidence suggests that flowing water may be a minimum requirement for nesting (Johnson et al. 1999). Along the Rio Grande in New Mexico, for example, reproduction crashed in the absence of river flows between April and June (Johnson et al. 1999). At the Colorado River Delta, the presence of surface water was the most important condition determining bird richness, abundance, and diversity, and the value of both native and saltcedar-dominated sites was dependent on water availability (Hinojosa-Huerta 2006). Water availability might confound any comparison of bird communities in native and non-native habitat, since saltcedar tends to dominate dry areas where reduced flows and groundwater drawdown no longer support cottonwood-willow forests (Hinojosa-Huerta 2006, Stromberg et al. 2009, Merritt and Poff 2010).

Climate Change

Riparian systems of the Colorado River Basin are not only threatened by past alterations but by continued impacts of climate change. Declines in water supply, increases in temperature and aridity, and disruptions in phenology are projected across the Southwest (Perry et al. 2012, USBR 2012). These climate-driven changes are likely to reduce flows and increase vulnerability more than projected development (USBR 2012). The unusually warm period from 2000 to 2014 was the worst 15-year drought on record and flows on the Colorado River were 19% below the twentieth century average (Udall and Overpeck 2017). As drier conditions become the norm across the Southwest, sustaining water supplies for natural systems and human use will become more challenging (Cayan et al. 2010). Extreme conditions are likely to push organisms beyond what they can tolerate in parts of the arid southwest (Seavy et al. 2009, Stromberg et al. 2012).

Climate change is predicted to reduce precipitation, snowpack, and streamflow (Hamlet et al. 2005, Stewart et al. 2005, Cayan et al. 2010, Vano et al. 2014, Fyfe et al. 2017). In the Colorado River Basin, flows are expected to continue to decline over the next century. The Bureau of Reclamation looked across a range of potential futures and estimates a median probable decrease of 9% by 2060 compared to the last century (USBR 2012). Uncertainty in projected precipitation under a changing climate means that some of those futures include increased flows (Harding et al. 2012). However, recent work suggests that increasing temperatures may impact flows more than precipitation rates. Between 2000 and 2014, one third of water loss was due to warming temperatures rather than decreased precipitation. Projected temperature changes alone could result in at least a 20% loss of flow by mid-century and as much as 50% or more loss by end of century (Udall and Overpeck 2017). Furthermore, across the western U.S., snowpack could decline 60% in the next 30 years (Fyfe et al. 2017). More precipitation falling as rain combined with earlier, slower snowmelts may actually reduce surface flows in snowmelt-dominated systems (Berghuijs et al. 2014, Barnhart et al. 2016).

Impacts of climate change will vary based on location within the basin. In the upper Colorado River Basin, small perennial headwater streams are more likely to become intermittent (Reynolds et al. 2015). On unregulated rivers, reduced flows may imitate the effects of flow regulation (Perry et al. 2012), resulting in further losses of native cottonwood-willow forests. On dammed rivers, flow regulation may override the effects of climate change in the near term, making the effects more dependent on human responses to climate change (e.g., flow regulation and increasing demand) than on climate change itself (Seavy et al. 2009, Perry et al. 2012). In the long-term, the ability of regulated rivers to deliver sufficient water at the times of year necessary to support functioning ecological processes, such as vegetation establishment, is at risk in every river within the Colorado River Basin. The Bureau of Reclamation has quantified this risk on four rivers (Figure 8) where more than 70% of future climate scenarios resulted in conditions that severely limit the availability of water for environmental values by mid-century, including along the mainstem Colorado River at the Colorado-Utah state line, the Green, Yampa, and San Juan rivers. These projections suggest that ecological flows in the upper basin are particularly vulnerable to climate change.

Groundwater recharge is expected to decrease as well, declining by an average of 10-20% across the Southwest over the next century (Meixner et al. 2016). In the San Pedro aquifer, reductions in precipitation are expected to result in double the decline in recharge, and declines in recharge will reduce streamflow in half by the end of the century, potentially resulting in a third of the riparian vegetation lost (Serrat-Capdevila et al. 2007). These changes are likely to have substantial impacts on riparian birds, as the San Pedro River is one of the last unregulated reaches that has maintained cottonwood-willow habitat with perennial flows (Brand et al. 2011). Reduced precipitation and increased evaporation will also cause droughts to become more prevalent and extreme in the future (Cayan et al. 2010, Perry et al. 2012, Udall and Overpeck 2017). Over the next 50 years, droughts lasting 5 years or more are likely to become the norm (USBR 2012). Riparian resilience to drought in the past might not be replicated in the future, as conditions outside the range of natural variability become more pervasive (Hinojosa-Huerta et al. 2013). The effects of climate change on water resources are likely to be exacerbated by a growing human population (Nilsson and Berggren 2000, Perry et al. 2012). The population of the basin states is projected to increase by over 7 million people by 2030 (ProximityOne 2017). By 2060, water needs across the Colorado River Basin are projected to outpace supplies by over 3 million acre-feet (USBR 2012). Increasing water development in any reach of the Colorado River Basin has the potential to eliminate riparian vegetation (Webb and Leake 2006). As water use increases with population growth and water supplies decrease with climate change, riparian ecosystems and the birds that depend on them will be under increasing pressure (Merritt and Poff 2010).

Species themselves may also be inherently sensitive to climate change. Langham et al. (2015) characterized climate change sensitivity by predicting where climatic conditions currently occupied by each species are likely to be found in the future (Table 4, Langham et al. 2015). Sandhill Crane, Willow Flycatcher, and Bell's Vireo are all classified as climate threatened, suggesting that the future climate in half of their current range will no longer be similar to climates where the species is found today, even under the mildest scenarios of future warming. This assessment is based on the continental range of each species and does not consider subspecies; vulnerability for regional populations or subspecies (e.g. Yuma Ridgway's Rail, Southwestern Willow Flycatcher, and Western Yellow-billed Cuckoo) in the Colorado River Basin is likely higher due to the magnitude of projected changes in climate and the corresponding impacts on river flows and habitat.

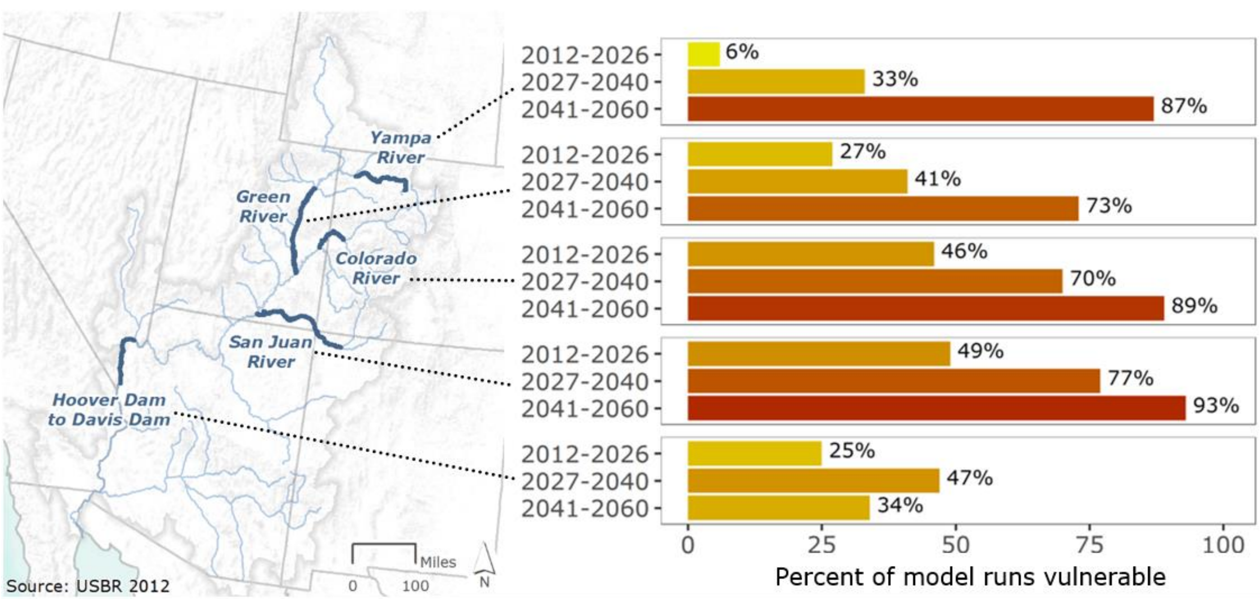

Figure 8. Ecological climate vulnerability of representative river segments in the Colorado River Basin based on the U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study (USBR 2012). Vulnerability is based on the ability of each river segment to meet water needs for environmental values (e.g., endangered species, cottonwood-willow regeneration, and minimum flow requirements) taking into account other uses as determined by current law and climate-driven changes in precipitation. A higher percentage of all model runs in which ecological water needs could not be met corresponds with high vulnerability.

Table 4. Range-wide climate sensitivity of priority Colorado River Basin species (Langham et al. 2015). Sensitivity status is defined by projected loss and gain of a species' climatically suitable range. Climate endangered species are projected to lose more than half of their current range by mid-century, with no net gain from potential range expansion. Climate threatened species are projected to lose more than half of their current range by the end of the century, with possible net gain from potential range expansion. Climate stable species are projected to lose less than half of their range by the end of the century. Climate sensitivity was assessed at the species level; subspecies or regional populations were not evaluated.

Priority Species	Climate Sensitivity
Ridgway's Rail	Threatened
Sandhill Crane	Threatened
Yellow-billed Cuckoo	Stable
Willow Flycatcher	Threatened
Bell's Vireo	Threatened
Yellow Warbler	Stable
Yellow-breasted Chat	Stable
Summer Tanager	Stable

Climate change will also advance phenology, leading to mismatches in the timing of floods, seed release, insect hatching, tree flowering, and the life cycle of migratory birds (Fontaine et al. 2009, Perry et al. 2012). Between 1948 and 2002, the onset of snowmelt advanced by 1-4 weeks across the western U.S. (Stewart et al. 2005). Shifts in snowmelt timing may lead to the decoupling of spring floods and native seed dispersal on snowmelt-dominated rivers, reducing cottonwood-willow forest regeneration (Shafroth et al. 1998, Hamlet et al. 2005, Stewart et al. 2005, Perry et al. 2012). Late-season surface flows will also decline with earlier snowmelt, making it even more difficult for young seedlings to survive (Shafroth et al. 1998, Perry et al. 2012). On monsoon-dominated rivers, like the San Pedro River, winter and summer floods may increase in magnitude, with mixed effects on native vegetation (Perry et al. 2012): increased winter flooding may benefit cottonwood-willow forests, which established along the San Pedro River during a period of intense winter flooding (Webb and Leake 2006), but increased summer flooding is likely to wash away native seedlings and favor germination of saltcedar, which releases seeds throughout the summer (Shafroth et al. 1998). Changes in phenology will be particularly disruptive for migratory birds, which depend on a variety of habitats throughout their life cycle (Fontaine et al. 2009). Bird migration through the Colorado River Basin is synchronized to the flowering of honey mesquite (McGrath et al. 2009, Perry et al. 2012). Emergence from winter dormancy and spring budburst are primarily controlled by temperature, and are expected to occur earlier as temperatures warm (Perry et al. 2012). As spring temperatures in stopover habitats increase faster than summer temperatures in breeding habitats, birds will face a difficult tradeoff between optimizing food supply at stopover habitat and reproductive success on breeding grounds, with serious consequences on survival and reproductive success (Carlisle et al. 2009, Fontaine et al. 2009).

Knowledge Gaps

In the Colorado River Basin, the past century has brought many changes in hydrology and riparian vegetation, and birds have responded. Local populations for multiple species are in decline and in need of conservation attention. Given the scope of potential future change, the Colorado River Basin merits additional attention to establish credible baseline abundance estimates across the basin and to understand the population-level effects of decreasing water availability and changes in vegetation. In order to achieve these goals, we recommend directing further research towards the following areas:

- Coordinated, standardized monitoring of bird populations throughout the Colorado River Basin to allow for detection of both local and regional trends in abundance over time.
- Further investigate the impact of saltcedar on bird populations and demographic processes. Current studies are limited in number and geographic extent and further understanding of these trade-offs are needed to inform restoration throughout the basin, including impacts of biological control efforts through the introduction of the saltcedar beetle.
- Explore the relative impacts of vegetation change and declining surface water to understand which is more harmful to bird populations.

SOLUTIONS THAT WORK: BRINGING A DESICCATED DELTA BACK TO LIFE

Mouth of the Colorado River by Ron Reiring / Flickr CC (BY-SA 2.0)

The 2014 Colorado River pulse flow taught us just how resilient habitat can be. For nearly two decades, the river had failed to reach the sea. But in 2014, billions of gallons of water flowed for eight weeks to its long-dry delta as part of the agreement between the U.S. and Mexico. The Colorado River "pulse flow" proved that a limited return of water can have immediate impacts on even on the most desiccated of landscapes, providing a scientific argument for continued work in this area. A 2016 International Boundary and Water Commission (IBWC) report on the pulse flow describes the results: newly germinated plants and increases in bird diversity and abundance. Further studies will help demonstrate if these impacts will hold.

- Further study of vegetation change and bird responses in the upper basin and headwaters of New Mexico, Colorado, Utah, and Wyoming. The bulk of scientific research has occurred along the mainstem Colorado River and tributaries of the Gila River. Further field studies are needed in the upper basin, as well as population estimates for riparian obligate birds.
- Basin-wide estimates of wetland, cottonwood, willow, mesquite, and saltcedar extents that can be updated regularly utilizing remotely sensed imagery.
- Focused monitoring of bird response to climate extremes in the lower Colorado River Basin.
- Improved estimates of future precipitation regimes and flow declines accompanying climate change.
- Improved indicators of local vulnerability to climate change by updating the Bureau of Reclamation Basin Study (USBR 2012). Metrics of ecological vulnerability could be improved through incorporation of additional information, such as sediment transport dynamics, that are known to impact cottonwood recruitment by creating substrate for establishment. Updated indicators at key river segments could be incorporated through the development of RiverWare hydrological models (Alexander et al. 2013).

Conclusions and Future Strategy

Over the last century, riparian habitats and the birds that rely on them have experienced tremendous change. Water development, including damming, flow regulation, surface water diversion and lake and groundwater extraction, has been the primary cause of the decline of native riparian trees and shrubs, which depend on high water tables for persistence and periodic flooding for regeneration. Changes in hydrology have facilitated the spread of non-native plants in marginal habitats throughout the basin, resulting in a net gain in vegetation, but a loss in habitat quality. Concurrent with this decline in habitat, at least six breeding birds that were once common within the Colorado River Basin experienced regional declines, including Western Yellow-billed Cuckoo, Southwestern Willow Flycatcher, Bell's Vireo, Yellow Warbler, Yellow-breasted Chat, and Summer Tanager. The declines of Yuma Ridgway's Rail, Western Yellow-billed Cuckoo, and Southwestern Willow Flycatcher led to their federal listing under the Endangered Species Act, and Bell's Vireo is state listed in California (Arizona subspecies) and New Mexico. Additionally, small regional populations of Sandhill Crane and Summer Tanager suggest these populations are vulnerable to future change. The future is daunting, with anticipated increases in demand from regional human population growth and climate change-induced reductions in flow leading to further loss of native riparian habitats with negative impacts on birds.

Audubon, with our partners, has developed a multi-pronged approach across the basin. Working with water users and stakeholders to increase water supply reliability and resiliency is our best opportunity to improve habitats. Increasing the sustainability of water ultimately enhances prospects for improved environmental flow management and restoration of rivers across the whole Colorado River Basin, including at specific sites most important to birds. Additionally, Audubon's wide-reaching network of members, chapters, and supporters continue to be engaged across the West in work to influence water policies and water management.

With more than 36 million people and 15% of U.S. agricultural output dependent on water from the Colorado River, human water needs surpass what the river can supply, and birds are at risk of losing the river flows that create the riparian and freshwater habitat they depend on. Without reform, today's water management framework could lead to severe water shortages to large numbers of people and economic production, likely resulting in political crisis. In that circumstance, it will grow increasingly difficult to advocate successfully that water should remain or be restored in rivers for nature's sake. An important step in protecting the birds of the Colorado River Basin is thus to improve the reliability and resiliency of the water supply for people as well as nature. Solutions include incentives for water conservation in both urban and rural communities, water-sharing agreements such as water banks, joint conservation funding agreements, and treaty agreements, as well as policy reforms that provide the flexibility to make these approaches successful. Without this platform, local efforts to protect and restore rivers throughout the basin are vulnerable. At the same time, Audubon is working to improve the reliability of the water supply for birds in some of the most important landscapes in the Colorado River Basin, including at the Colorado River Delta, Gila River, and Salton Sea.

Working with partners, Audubon can facilitate solutions that put water users across the Colorado River Basin out of crisis mode with more reliable and resilient water supplies. These near-term wins will enable Audubon to protect and restore the Colorado River Basin for birds in the long-term by:

- Preventing continued dewatering of rivers, lakes, wetlands and associated habitats,
- Growing support for and development of water markets to restore flows,
- Defining priority river reaches for restoration and improved habitat connectivity, and
- Increasing the dollars available for water conservation and habitat restoration.

Through this strategy and on-the-ground partnerships with water users, Audubon will improve and safeguard stream flows and riparian habitat.


Salton Sea by Juan C. Ramon / Flickr CC (BY-SA 2.0)

SALINE LAKES AND WETLANDS OF THE INTERMOUNTAIN WEST

Overview and Importance

Bordered by the Rocky Mountains to the east and the Sierra Nevada and Cascade Ranges to the west, the Intermountain West is the most important inland region for shorebirds in North America, supporting at least 11 breeding species, 23 migrant species, and millions of individuals (Brown et al. 2001, Oring et al. 2013). In this arid landscape, saline lakes and their associated wetlands provide essential habitat for waterbirds, shorebirds, and waterfowl (Jehl 1994, Oring and Reed 1997, Reed et al. 1997, Brown et al. 2001, Oring et al. 2013). Over 99% of the North American population of Eared Grebes, up to 90% of Wilson's Phalaropes, and over 50% of American Avocets stop at saline lakes in the Intermountain West, and large colonies of American White Pelicans (up to 50% of the global population) and Western Snowy Plovers breed at these sites (Brown et al. 2001, Paul and Manning 2002, Ellis and Jehl 2003, Oring et al. 2013). Great Salt Lake and the Lahontan Valley wetlands are recognized as WHSRN sites of hemispheric importance, supporting over 500,000 birds annually (IWJV 2013). Mono Lake and the Salton Sea are recognized as sites of international importance, supporting over 100,000 birds annually. A number of other saline lakes surpass WHSRN requirements for international importance, including Lake Abert, Owens Lake, and Summer Lake; and Honey Lake surpasses requirements for regional importance, supporting over 20,000 birds annually (Brown et al. 2001, IWJV 2013, Oring et al. 2013). National Wildlife Refuges have been established at five of the eleven priority lakes discussed in this report (Great Salt Lake, Pyramid Lake, Lahontan Wetlands, Klamath Basin, and the Salton Sea), and State Wildlife Management Areas or Reserves have been established at another four (Honey Lake, Owens Lake, Mono Lake, and Summer Lake) (USFWS 2016, CADPR 2017). All of these sites are recognized as IBAs due to their large concentrations of birds (BirdLife International 2017).

Ecology of saline lakes and associated wetlands

Saline lakes are landlocked waterbodies often referred to as terminal lakes because they occupy closed basins with no outlets. Freshwater inputs are often seasonal, typically arriving in winter and spring from precipitation- and snowmelt-fed rivers (Jehl and Johnson 1994). Incoming salts and minerals accumulate, as water is lost only through evaporation and diversions. Terminal lakes are considered saline when salinity reaches 3%, and hypersaline when salinity surpasses that of sea water (3.5%). High concentrations of carbonate salts can also make some saline lakes alkaline (i.e. pH > 7, Jehl and Johnson 1994).

Saline lakes in the Intermountain West formed over 20,000 years ago under a cooler and wetter climate and covered more than 25 million acres at their peak (Engilis and Reid 1996). Today, smaller remnants of these lakes exist in the Great Basin, including at Great Salt Lake and the Lahontan Wetlands; in the eastern drainages of the Cascade Range, including at Lake Abert and Summer Lake; and in the eastern drainages of the Sierra Nevada, including at Mono, Owens, Pyramid, and Honey Lakes (Figure 9). In addition, the Salton Sea is located in the Sonoran Desert and is currently sustained by inflows and agricultural runoff from the Colorado River. The Colorado River Delta and Klamath Basin, although not saline lakes *per se*, are also included as priority sites in this portion of this report because they provide similar valuable habitat for shorebirds, waterbirds, and waterfowl in this region.

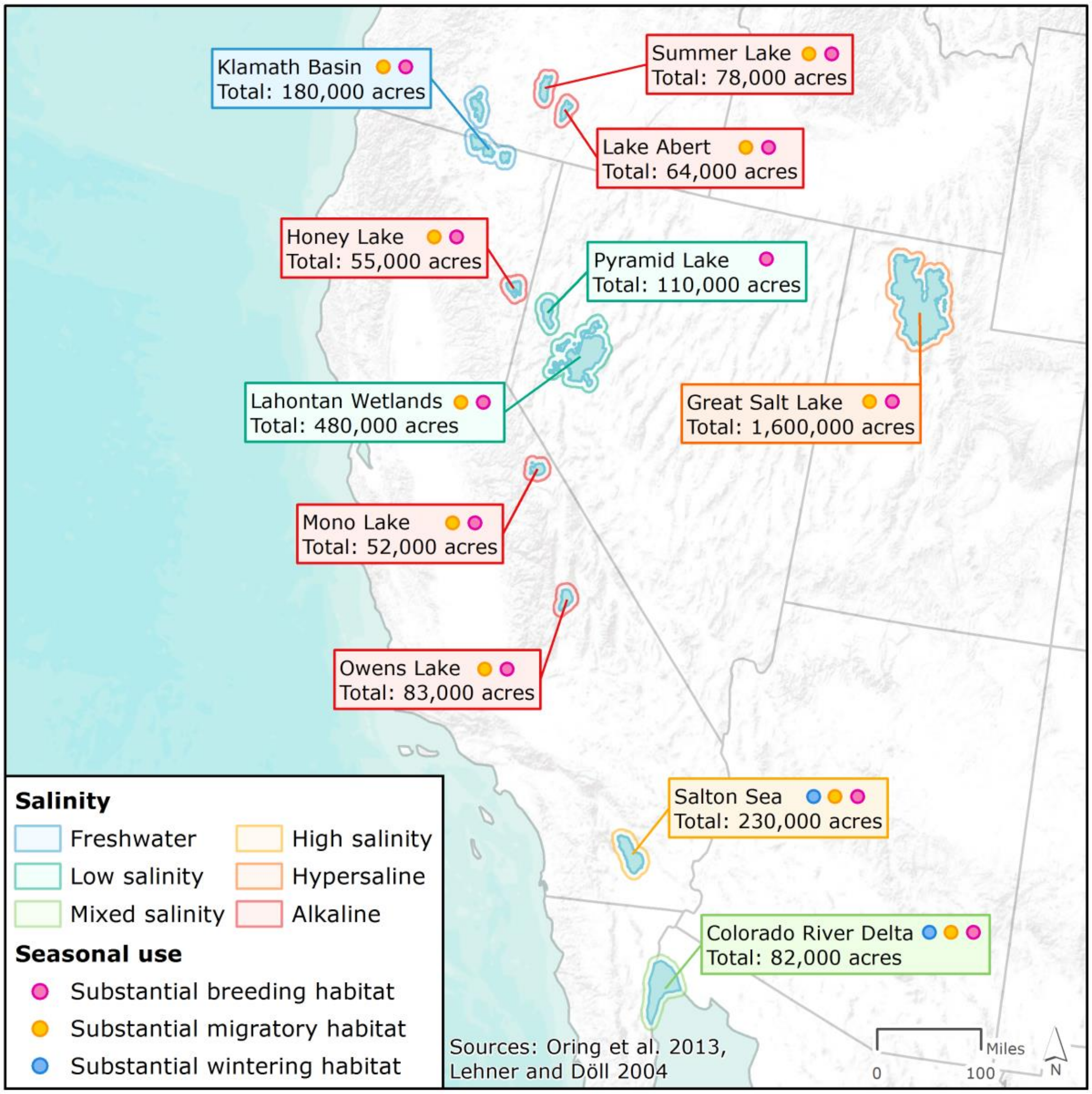

Figure 9. Priority saline and freshwater lakes of the Intermountain West, their typical salinity, and seasonal use by birds. Total acreages include both permanent and intermittent open water and wetlands and reflect conditions in the early 2000s based on a global dataset of lakes and wetlands developed with a standardized methodology (Lehner and Doll 2004). Values are shown to depict relative size and may differ from more recent, local estimates of available open water and wetland habitats.

Saline lakes provide a diversity of habitats used by birds, including wetlands, deltas, mudflats and playas, islands, and open water of varying depths. Wetlands occur along the edges of saline lakes and at the outlets of freshwater rivers emptying into the lakes (Jones et al. 2016). These freshwater inflows create a gradient of fresh to brackish to saline conditions to which wetland vegetation responds (Ma et al. 2009). The complex of open water, emergent marshes, and wet meadows surrounding the outlets of freshwater rivers provide forage and shelter for both migrating and breeding waterfowl and waterbirds, including Ruddy Duck, White-faced Ibis, and Wilson's Phalarope (Ma et al. 2009, UTDNR 2013). Any decline in these inflows impacts the salinity gradient and pH of the water and can reduce the quality and extent of wetland habitats (Jones et al. 2016).

Rivers also bring sediments to saline lakes that build riverine deltas heavily used by birds (UTDNR 2013). The low elevation gradient in many saline lake shorelines also results in large extents of both deep and shallow water habitats (UTDNR 2013, Jones et al. 2016). Playas are lake-bottom depressions remnant of ancient lakes that contain expanses of exposed sediment and are used by many shorebird species, such as Western Snowy Plover, for nesting. Mudflats and shallow water (<0.5 feet) provide critical foraging habitat for shorebirds, including Marbled Godwit, Western Sandpiper, American Avocet, Black-necked Stilts, and Western Snowy Plover. Deep water (>1 foot) is occupied by waterfowl and waterbirds, including American White Pelican, Eared Grebe, and Wilson's Phalarope.

Saline lakes naturally fluctuate in both water volume and salinity over time in response to climate (Oviatt 1997, Licciardi 2001). Over thousands of years, conditions may range from small, ephemeral ponds to large, stable lakes (Jehl and Johnson 1994, Herbst 2001). Food webs at saline lakes are salinity-controlled, affecting what prey are available to waterbirds (Herbst et al. 2014). In a simple saline lake food web, algae are the primary producers, invertebrates and fish are the primary consumers, and waterbirds are the primary predators (Larson and Larson 2011). Biotic diversity varies inversely with salinity: lower salinity fosters greater species diversity, but at lower abundances, while higher salinity fosters lower diversity, but at higher abundances (Mahoney and Jehl 1985, Jehl and Johnson 1994, Paul and Manning 2002, Jehl 2007). Low-salinity lakes, such as Pyramid Lake, are home to diverse biotic communities, including a variety of fish, crustaceans, insects, and other prey, which in turn support a variety of waterbirds, including piscivorous species like American White Pelican, Common Loon, grebes, and cormorants (Rubega and Robinson 1996, Herbst 2001, Ma et al. 2009, Herbst et al. 2014). Hypersaline lakes, such as Mono Lake and some of the bays of Great Salt Lake, are dominated by a few superabundant invertebrates, including brine shrimp, alkali flies, and chironomids, which in turn support huge numbers of insectivorous waterbirds and shorebirds, including Eared Grebe, American Avocet, and Wilson's Phalarope (Rubega and Robinson 1996, Herbst 2001). Some birds have developed adaptations to high salinity, including the ability to obtain all of their freshwater requirements from their prey, avoid ingesting lake water while feeding, and excrete excess sodium chloride through salt glands (Mahoney and Jehl 1985, Jehl 1988, Rubega and Oring 2004). Other birds that use saline lakes, including Western Sandpiper, Red-necked Phalarope, and juvenile American Avocet may prefer habitats near freshwater inputs (Ma et al. 2009, Jones et al. 2016) or regularly travel to adjacent wetlands or other waterbodies to meet their needs for freshwater (Rubega and Robinson 1996).

Status of Priority Species

Priority species identified in this report are representative of the diversity of birds that inhabit saline lakes and their associated wetlands (Table 5). They include waterfowl (Ruddy Duck), waterbirds (Eared Grebe, American White Pelican, and White-faced Ibis), and shorebirds (American Avocet, Western Snowy Plover, Marbled Godwit, Western Sandpiper, and Wilson's Phalarope). Highlighting the critical importance of saline lakes is the fact that high counts of single species at these lakes can exceed millions of birds, while a number of sites support hundreds of thousands of birds at any given time (Table 6).

Some of these priority species are currently in decline globally or regionally (Table 5). Migratory shorebird populations, in particular, have declined by nearly 70% since 1973 (NABCI 2016, Senner et al. 2016). Western Snowy Plover and Wilson's Phalarope are declining globally. Regional populations of Eared Grebe, White-faced Ibis, Western Snowy Plover, and Marled Godwit are of conservation concern (Table 5). Local population counts also show declines. Wintering Eared Grebes at the Salton Sea have gone from millions in the 1980s (Jehl 1988) to hundreds of thousands in 1999 (Shuford et al. 2000) and tens of thousands more recently (A. Jones, pers. comm.). It's unknown if these local changes reflect a redistribution of wintering birds among lakes or overall population declines. All priority species are migratory and therefore regulated species under the Migratory Bird Treaty Act.

Table 5. Saline lake priority species, description of preferred habitat, conservation status, global population estimate, high count in the saline lake network, and population trend.

Priority Species	Preferred Habitat[1]	Conservation Status[2]	Global Population Estimate[3]	High Count at Saline Lakes[4]	Global Population Trend[3]
Ruddy Duck	Breed in prairie pothole region. Use marshes, ponds, and reservoirs with extensive vegetation and open water. Use large, permanent wetlands and lakes during migration. Winter in inland and coastal wetlands.	No special federal or state status. Threatened by contamination and loss of wetland habitat.	485,000	97,700 (Klamath Basin, Fleskes and Yee 2007)	Stable
Eared Grebe	Inhabit shallow lakes and ponds with emergent vegetation in the breeding season. Prefer saline habitats in all other seasons.	No special federal or state status. Threatened by loss and degradation of wetland habitat. USFWS Species of Conservation Concern in the Great Basin Bird Conservation Region (BCR).	4,148,000	4,700,000[5] (Great Salt Lake, Neill et al. 2016)	Stable
American White Pelican	Nest on lake islands, forage in marshes, lakes, or rivers. Nesting and foraging habitat are often far apart (>30 miles). Winter in coastal wetlands, and saline lakes.	No special federal or state status. Sensitive to disturbance at nesting sites. Threatened by contamination and loss of wetland habitat.	157,000	85,000 (Great Salt Lake, Paul and Manning 2002)	Unknown
White-faced Ibis	Breed in shallow, vegetated marshes. Forage in nearby irrigated agriculture and shallow wetlands. Use mudflats along rivers and lakes during migration. Winter in inland and coastal wetlands and flooded agricultural fields.	Great Basin population has been designated as a sensitive species, species of management concern, and candidate for federal listing by the U.S. Fish and Wildlife Service. Threatened by water diversion, habitat loss, contamination, and disturbance of nesting sites.	1,150,000	37,438 (Salton Sea, Howell and Shuford 2008)	Increasing
American Avocet	Inhabit salt lakes, alkaline wetlands, mudflats, and potholes. Prefer open shallow waters. Nest on islands and shorelines (mudflats).	No special federal or state status. Threatened by contamination and loss of wetland habitat.	450,000	252,358 (Great Salt Lake, Shuford et al. 2002)	Stable
Western Snowy Plover	Nest on bare or sparsely vegetated beaches of saline or alkaline lakes, salt flats, rivers, islands, or	Pacific Coast population listed as federally threatened in 1993. State listed as endangered in Washington; threatened in	25,870	5,511 (Great Salt Lake,	Declining (Pacific coast population), Unknown

Priority Species	Preferred Habitat[1]	Conservation Status[2]	Global Population Estimate[3]	High Count at Saline Lakes[4]	Global Population Trend[3]
	coastal beaches. Winter primarily in coastal beaches and saline lakes.	Oregon. USFWS Species of Conservation Concern in the Great Basin BCR. Threatened by habitat degradation and loss, contamination, predation, and disturbance of nesting sites.		Thomas et al. 2012)	(Interior population)
Marbled Godwit	Breed in grasslands and wetlands with short vegetation. Prefer ephemeral and alkaline wetlands. Migrate through inland and coastal wetlands. Winter in coastal wetlands.	No special status, but usually ranks high as a shorebird species of conservation concern. Threatened by loss of grassland and wetland habitat. USFWS Species of Conservation Concern in the Great Basin BCR.	174,000	43,000 (Great Salt Lake, Paul and Manning 2002)	Stable
Western Sandpiper	Breed in artic and sub-arctic coasts to uplands. During migration, prefer habitat at the margins of saline lakes and ponds at inland sites; intertidal mudflats and sandflats at coastal sites. Winter primarily in coastal wetlands.	Listed as a species of high concern by the U.S. and Canada Shorebird Conservation Plans. Threatened by contamination and loss of wetland habitat. Particularly vulnerable to trophic mismatch under climate change as a long-distance migrant.	3,500,000	190,000 (Great Salt Lake, Paul and Manning 2002)	Stable
Wilson's Phalarope	Breed primarily in inland wetlands. Use open saline water in interior portions of hypersaline lakes during fall migration for roosting and molting as well as adjacent wetlands and shallow wetlands and coastal marshes during spring migration. Winter in salt lakes, alkaline ponds, and freshwater marshes in South America.	No special federal or state status, but Great Salt Lake, Mono Lake, and Laguna Mar Chiquita designated as WHSRN sites in recognition of their importance to this species. Threatened by water diversion and loss of wetland habitat.	1,500,000	603,000 (Great Salt Lake, Jehl 1999)	Declining

[1] Habitat descriptions are from Birds of North America Online species accounts (Poole 2005).

[2] Conservation statuses are from Birds of North America Online species accounts (Poole 2005) and the USFWS Species of Conservation Concern (USFWS 2008). All priority species are protected under the Migratory Bird Treaty Act.

[3] Global population estimates and trends are from the Waterbird Population database (Wetlands International 2017) for waterbirds and Andres et al. (2012) and Senner et al. (2016) for shorebirds.

[4] High counts represent the single highest count or abundance estimate in the saline lake network for each species, and are taken from multiple sources published in the last 20 years.

[5] The high count for Eared Grebe is greater than the total population estimate, likely due to improvements in survey techniques.

Table 6. High counts of priority saline lake species at priority sites. Counts are from various sources, years, and seasons published in the last 20 years (1997-2017). Species are sorted taxonomically and sites are sorted by latitude.

	Ruddy Duck 3, 12, 20	Eared Grebe 4, 5, 9, 20, 21, 22	American White Pelican 6, 9, 18, 20	White-faced Ibis 11, 13, 18, 19, 20	American Avocet 7, 9, 10, 18, 20	Snowy Plover 7, 8, 9, 16, 17, 20	Marbled Godwit 1, 6, 7, 20	Western Sandpiper 1, 6, 7, 14, 18	Wilson's Phalarope 2, 7, 15, 17, 18, 20, 23
Colorado River Delta	1-500	1-500	501-1,000	1-500	1,001-10,000	1-500	1,001-10,000	50,001-100,000	1,001-10,000
Salton Sea	10,001-50,000	> 1,000,000	1,001-10,000	10,001-50,000	10,001-50,000	1-500	1,001-10,000	50,001-100,000	1,001-10,000
Owens Lake	1,001-10,000	10,001-50,000	1,001-10,000	1-500	10,001-50,000	1-500	501-1,000	10,001-50,000	1,001-10,000
Mono Lake	1,001-10,000	> 1,000,000	501-1,000	1-500	10,001-50,000	1-500	1-500	10,001-50,000	> 100,000
Lahontan Wetlands	501-1,000	1-500	501-1,000	10,001-50,000	50,001-100,000	1-500	501-1,000	50,001-100,000	50,001-100,000
Pyramid Lake	501-1,000	1-500	10,001-50,000	1-500	1-500	1-500	1-500	1,001-10,000	1-500
Honey Lake	1-500	1-500	1-500	1-500	1,001-10,000	1-500	1-500	1,001-10,000	1-500
Great Salt Lake	50,001-100,000	> 1,000,000	50,001-100,000	10,001-50,000	> 100,000	1,001-10,000	10,001-50,000	> 100,000	> 100,000
Klamath Basin	50,001-100,000	10,001-50,000	1,001-10,000	1,001-10,000	1,001-10,000	1-500	1-500	10,001-50,000	1,001-10,000
Lake Abert	1-500	10,001-50,000	1-500	1-500	10,001-50,000	1-500	1-500	10,001-50,000	> 100,000
Summer Lake	1-500	1-500	1-500	501-1,000	10,001-50,000	501-1,000	1-500	1,001-10,000	1,001-10,000

Legend						
1-500	501-1,000	1,001-10,000	10,001-50,000	50,001-100,000	> 100,000	> 1,000,000

High counts are from the following sources: [1] Mellink et al. 1997, [2] Jehl 1999, [3] UTDNR 2000, [4] Jehl & McKernan 2002, [5] Jehl et al. 2002, [6] Paul & Manning 2002, [7] Shuford et al. 2002, [8] Strauss et al. 2002, [9] Shuford et al. 2004a, [10] Shuford et al. 2004b, [11] Hinojosa-Huerta 2006, [12] Fleskes & Yee 2007, [13] Howell & Shuford 2008, [14] Fernández et al. 2010, [15] Lesterhuis & Clay 2010, [16] Thomas et al. 2012, [17] Gomez-Sapiens et al. 2013, [18] Oring et al. 2013, [19] Cavitt et al. 2014, [20] eBird Basic Dataset 2016, [21] Larson et al. 2016, [22] Neill et al. 2016, [23] J. Jehl, pers. comm.

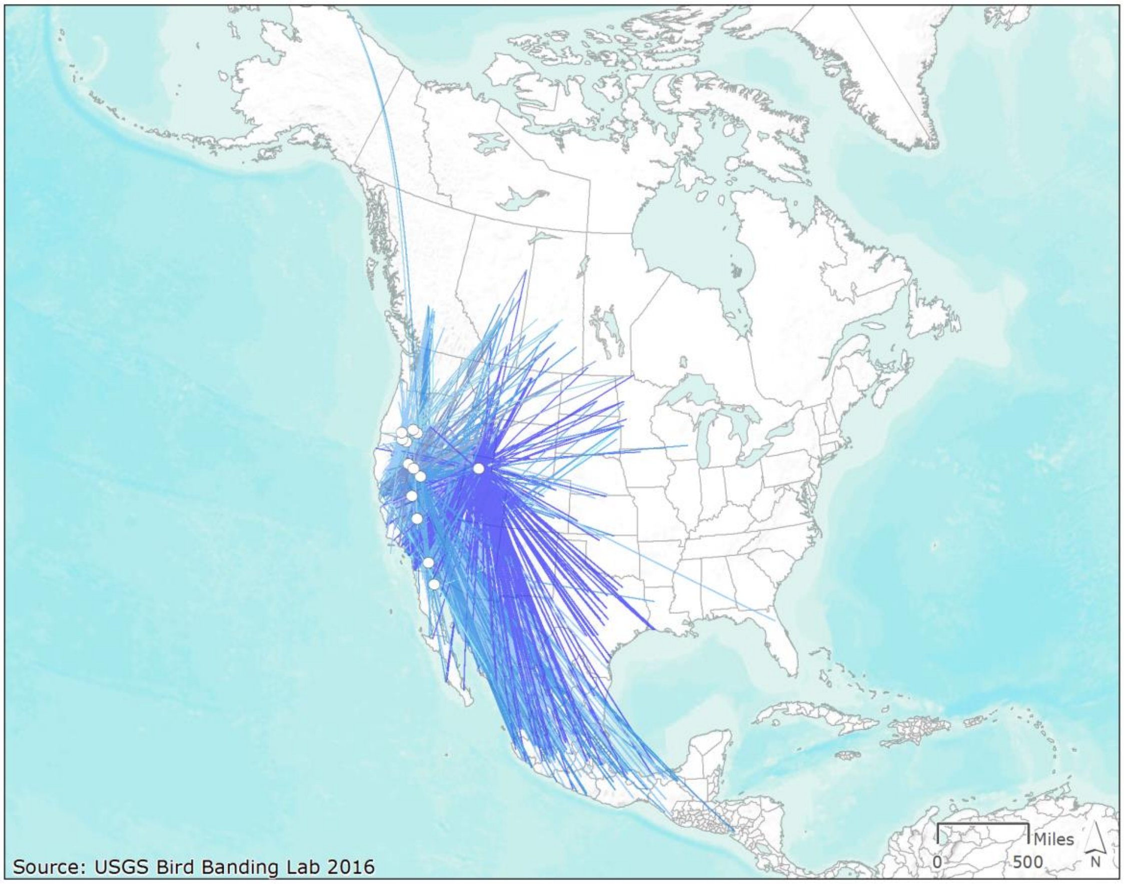

Figure 10. Movements of saline lake priority species across North America that originated or ended at saline lake priority sites. Saline lake priority sites are shown as white circles and movement paths are shown in shades of blue. Movement paths were generated based on banding and recovery locations from the USGS Bird Banding Laboratory database (USGS 2015). Banding records were not obtained for Marbled Godwit and Wilson's Phalarope.

Migratory Connectivity

Saline lakes and associated wetlands provide a much-needed link across global flyways (Engilis and Reid 1996). Banding records alone demonstrate migratory connectivity between priority lakes and the Pacific Coast, Arctic, Great Plains, Gulf Coast, Mexico, and Central America (Figure 10, USGS 2015). Many waterbirds use these sites as staging habitat, where they accumulate large fat loads in preparation for migration to Central and South America, including Wilson's Phalarope, which departs from staging areas on these lakes for a roughly 5,000-mile trip to Laguna Mar Chiquita in central Argentina (Jehl and McKernan 2002, Warnock 2010). Superabundant prey allow saline-tolerant species to congregate in large numbers, with some species like Eared Grebe doubling their weight within a few months (Jehl 1988, Jehl and McKernan 2002). For certain species, timing of departure from saline lakes coincides with a decline in prey abundance (Jehl 1988, Jehl 2007).

Both documented and hypothesized movements of priority species among saline lakes reveal how these sites function collectively to support migratory birds within the region, as well as populations from the Central Flyway to the east and Pacific Coast to the west (Figure 11). Great Salt Lake and the Salton Sea support the largest populations of birds and also have the most known migratory connections. Great Salt Lake is a true migration hub, serving birds going to and from breeding grounds in the Pacific Northwest and midcontinental prairies, and wintering grounds in the Gulf Coast, Mexico, Central and South America, and the Salton Sea. For example, Marbled Godwits from midcontinental and Pacific Northwest regions move through Great Salt Lake in spring and fall (Olson et al. 2014). The Salton Sea serves a similar, but more restricted, role in the spring by receiving birds from the Colorado River Delta and wintering grounds farther south that are in route to breeding sites in the Arctic, Pacific Coast, California's Central Valley, or other saline lakes along the eastern slopes of the Sierra Nevada and Cascade Ranges. In the fall, the Salton Sea receives birds from Great Salt Lake, Mono Lake, and other saline lakes, and the Pacific Coast. Western Sandpipers, in particular, follow this path through the Colorado River Delta and Salton Sea during spring and fall migration (Warnock et al. 2002, Shuford et al. 2004b). Less is generally known about the migratory connectivity among saline lakes located along the eastern slopes of the Sierra Nevada and Cascade Ranges. American Avocets have been documented moving among those lakes after breeding (Plissner et al. 1999, Plissner et al. 2000), perhaps before moving farther south. Species such as the Eared Grebe and Western Sandpiper are also hypothesized to leapfrog from lake to lake on their journeys north and south (Warnock and Bishop 1998, Bishop et al. 2006, Jehl and Henry 2010). New technologies in the study of migratory connectivity, including miniaturized trackers and genetic markers, provide new opportunities to document how species move throughout the network of saline lakes (Ruegg et al. 2014, Marra et al. 2015).

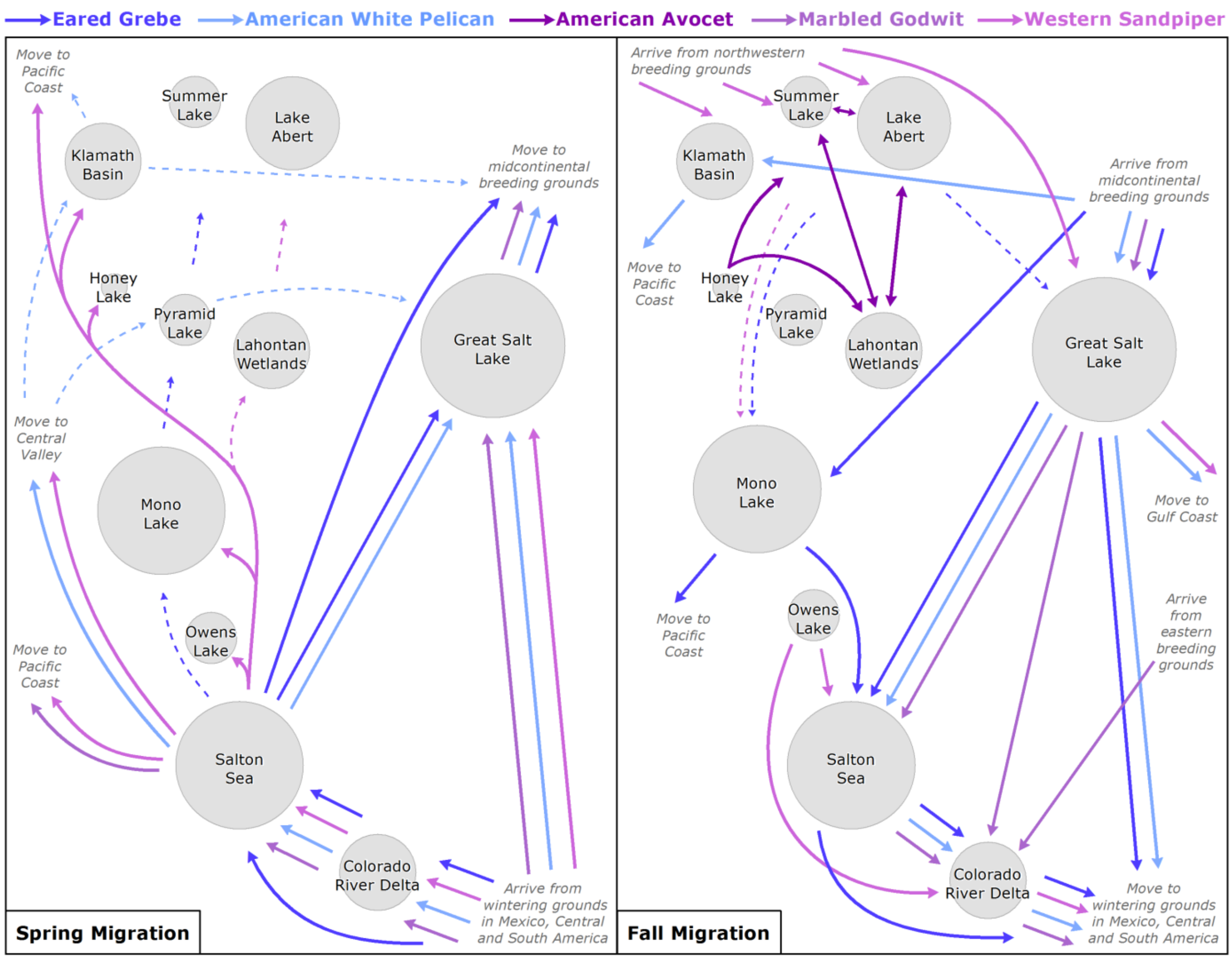

Figure 11. Generalized migration routes used by priority species during spring and fall. Waterbirds are depicted in blue and shorebirds in purple. Circle sizes scale to the maximum counts across priority species (Table 6). Routes are drawn based on expert opinion. Solid lines depict connectivity supported by empirical data, and dashed lines depict hypothesized connectivity. Individual species connectivity maps are available in Appendix B.

Due to their changing conditions and use by species, saline lakes and associated wetlands could be considered a single habitat network rather than independent units, and understanding connectivity within and among sites is essential for bird conservation (Haig et al. 1998). For migratory species, relatively small amounts of habitat loss at key staging sites can trigger disproportionate population declines (Taylor and Norris 2009, Iwamura et al. 2013). A few sites have already been lost (e.g., Winnemucca Lake in Nevada is now a dry lakebed). Others were drained at one time but now function as managed impoundments (e.g., Owens Lake). Still others may be on the brink of collapse (e.g., Lake Abert; Larson et al. 2016, Moore 2016) or massive ecological change caused by water diversions (e.g., Salton Sea; Jones et al. 2016).

Because saline lakes and associated wetlands are subject to rapid environmental change, species that rely on them also need to be flexible and opportunistic (Jehl 1988, Warnock et al. 1998). Waterbirds respond to changing conditions by moving among sites between seasons and years to meet their needs, fluctuating in relative abundance, adjusting their length of stay, and taking advantage of new habitats as they form, such as Owens Lake or the Salton Sea (Jehl 1988, Haig et al. 1998, Warnock and Bishop 1998). The survival of waterbirds in these variable habitats depends on the availability of back-up sites that birds can move to when habitat at one site fails (Jehl and Johnson 1994). For example, most White-faced Ibises bred at Great Salt Lake until floods in the mid-1980s inundated colonies, reducing the population by 80% (Earnst et al. 1998). Ibises relocated to the Lahontan Wetlands and Summer Lake, where colony sizes grew until drought in the early 1990s caused nesting colonies to fail again, and many ibises returned to Great Salt Lake (Earnst et al. 1998). However, if water levels decline simultaneously across sites, little redundancy is left in the network of western saline lakes (Jehl and Johnson 1994). Given the magnitude and ubiquity of threats to these systems, system collapse is a risk for the future.

Threats

Although saline lakes provide important habitat for shorebirds and waterbirds, conservation of these ecosystems has been largely ignored (Belovsky et al. 2011). Historically, wetland policies in the U.S. encouraged the destruction of these ecosystems, both directly, through draining and conversion, and indirectly, through diversions of inflows and lake water extraction (Engilis and Reid 1996, Pringle 2000). Nearly all saline lakes in the Intermountain West have decreased in size and increased in salinity as a result of the growing demand for water from agriculture, industry, and urban users as well as from climate warming (Grimm et al. 1997, Larson et al. 2016). Recognizing the importance of wetland habitats has not slowed the degradation of saline lake complexes (Lemly et al. 2000), and policies to protect wetlands have often been ineffective because they focus on conserving the land wetlands occupy, rather than the water needed to sustain them (Downard and Endter-Wada 2013). Appendix C provides detailed histories for each of the priority saline lakes.

Declining inflows

In the summers of 2014 and 2015, all lakes recognized as important habitat by the Intermountain West Joint Venture, including Great Salt Lake, Lahontan Wetlands, Klamath Basin, Lake Abert, Summer Lake, Honey Lake, and Mono Lake, were at their lowest levels or completely dry (Moore 2016). Historically, surface levels of saline lakes were balanced by inflows from streams, groundwater, and precipitation and water loss to evaporation (Arnow 1984). Changes in lake level were moderated by naturally occurring feedbacks: as lake levels decline under dry conditions, lake area decreases and salinity increases, which slows their evaporation rate, whereas the opposite occurs under wet conditions (Arnow 1984, Wurtsbaugh et al. 2016). As human activities over the last century have altered water cycles across the West, saline lakes no longer reflect this natural equilibrium (Moore 2016, Wurtsbaugh et al. 2016). It has been estimated that at Great Salt Lake, consumptive water uses over the past 150 years have reduced river inflows by 39%, leading to roughly an 11-foot drop in lake level and a 48% reduction in lake volume (Wurtsbaugh et al. 2016). At Lake Abert, recent inflows are less than half of what they have been historically, and the lake has declined to 5% of its maximum recorded area (Larson et al. 2016). Diversions from the Truckee River have caused lake levels at Pyramid Lake to decline by almost 70 feet since 1890 (Williams 2001). Diversions along the Carson River have led to the loss of 84% of the wetlands that once existed in the Lahontan Valley, and up to 90% of wetlands in the Klamath Basin have been lost due to water development along the Klamath River (Engilis and Reid 1996, Lemly et al. 2000). Inflows will drop by 40% in 2018 when the Imperial Irrigation District (IID) ends the flow of Colorado River water into the Salton Sea per a 2003 mitigation agreement (Jones et al. 2016).

Lake Winnemucca in Nevada is already completed desiccated, while others appear to be on their way if trends continue (Williams 2001, Moore 2016). Owens Lake, almost completely drained by 1918 from water diversions, is one example where a compromise between stakeholders arranged to return flows to the lake to create managed wetland and open water habitats for the benefit of wildlife (LADWP 2013).

Declining water quality

Issues of water quality are inseparable from water supply because concentrations of salts and contaminants vary with water volume (Arnow 1984, Pringle 2000). Terminal wetlands are particularly vulnerable to salinization because natural salt removal is limited (Jolly et al. 2008). Surface diversions upstream of saline lakes lead to increased salinity downstream, as lake volume decreases while salt quantities remain constant or increase (Williams 2001). Additionally, many terminal wetlands are located downstream of irrigated lands, often leading to increased contamination from agricultural runoff (Engilis and Reid 1996, IWJV 2013). Over the past century, salinities at many large terminal lakes in the Intermountain West have increased dramatically following upstream diversions and land use change, including at Lake Abert, where salinity increased over tenfold from 20 g/L to 250 g/L between 1986 and 2014; Mono Lake, where diversions led to a decline in lake volume by over 50% while salinity doubled from 50 g/L to 100 g/L between 1941 and 1981; and the Lahontan Wetlands, where concentrations of dissolved solids have increased by up to 100 times historical levels (Herbst 2014, Herbst and Prather 2014, Williams 2001). Contamination is inevitable at sites like the Salton Sea and the Colorado River Delta, where wetlands are maintained by agricultural and urban return flows diverted from the Colorado River (Cohen et al. 1999, Gomez-Sapiens et al. 2013). The runoff that maintains these waterbodies is loaded with salts, pesticides, and metals, including mercury and selenium (Schroeder et al. 2002, Vogl and Henry 2002). Selenium contaminates the food supply, including brine flies, and bioaccumulates in birds, with negative impacts on physiological and reproductive health (Heinz et al. 1989, Cavitt 2008, Wurtsbaugh 2009).

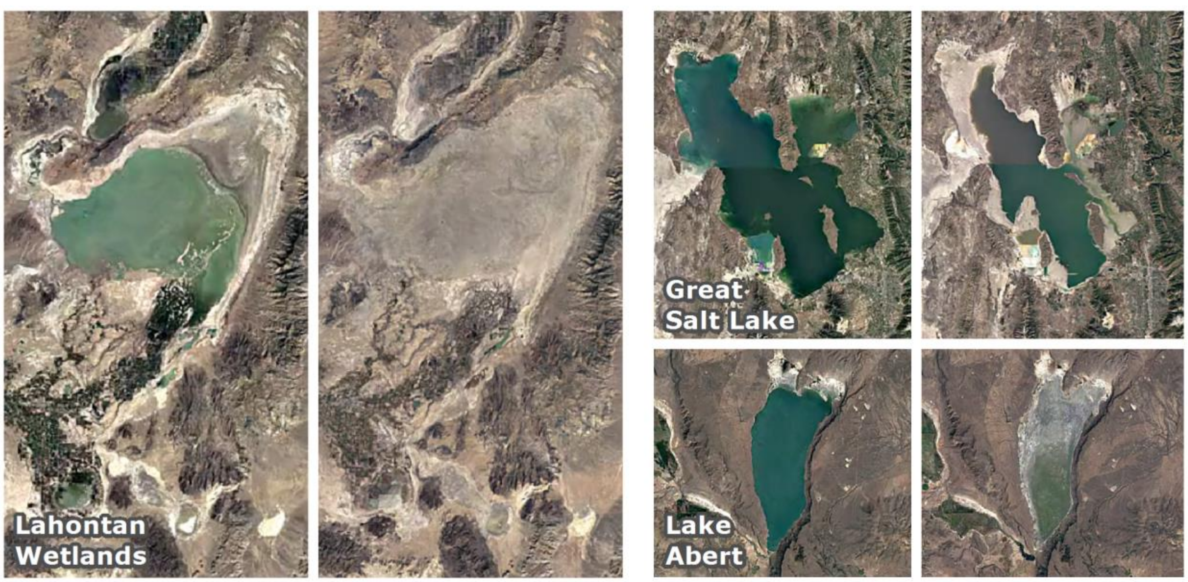

Figure 12. Side-by-side comparisons of satellite imagery for selected priority saline lakes in 1985 and 2015; two years separated in time for which precipitation across the western U.S. was similar for a two-year period (1984-85 and 2014-15).

Impacts on Birds

Declines in water inflows and quality have negatively impacted shorebirds, waterbirds, and waterfowl in the Intermountain West by reducing nesting and foraging habitat, altering food webs, and exposing birds to increased predation, contamination, and disease (Colwell and Taft 2000, Ma et al. 2009). Drought conditions in the early 2000s resulted in loss of wetland and aquatic habitat at Great Salt Lake, leading to a decline in duck populations and a reduction in habitat use by 33% compared to under wetter conditions (Vest 2013). Falling lake levels at Lake Abert led to declines in all of the most abundant waterbirds between 2011 and 2015, with declines in peak counts of phalaropes, from over 60,000 to under 13,000 birds, and Eared Grebes, from over 11,000 to less than 100 birds (Larson et al. 2016).

Low flows and heightened salinity are particularly harmful during the breeding season when waterbirds and their chicks depend on freshwater (Hannam et al. 2003). Even shorebirds adapted to hypersaline lakes, like American Avocet, require access to freshwater resources during the breeding season, as chicks raised in highly saline environments suffer from physiological stress, including dehydration and weight loss (Hannam et al. 2003).

Island-nesting species like American White Pelican and California Gull are particularly vulnerable to fluctuating water levels, especially during egg-laying and incubation, as rising water levels flood nests and declining water levels expose nests to increased predation and disturbance (Moreno-Matiella and Anderson 2005, Ma et al. 2009). In the Klamath Basin, even small changes in lake level have a big impact on which parts of the terrain become islands or peninsulas (Moreno-Matiella and Anderson 2005). On a number of occasions, American White Pelican nests have been lost to predation after islands in Clear Lake Reservoir became land-bridged; on one such incident in 1991 nearly 500 land-bridged nests were completely abandoned after just one adult was depredated (Moreno-Matiella and Anderson 2005). At Mono Lake, declining lake levels caused Negit Island to become land-bridged, exposing breeding grounds of California Gulls to predation from coyotes that decimated the colony (Blumm and Schwartz 1995, Herbst 2014). At Pyramid Lake, where Anaho Island supports the largest breeding colony of American White Pelican in western North America, pelican productivity is negatively correlated with the flow volume of the Truckee Canal, where flows have been diverted for agriculture since 1906 (Murphy and Tracy 2005). Colony production at Pyramid Lake could have been up to 58% higher without hydrologic alterations along the Truckee River (Murphy and Tracy 2005). At the Lahontan Wetlands, waterbird production has steadily declined with a diminishing water supply (Lemly et al. 2000). At Great Salt Lake, shallow nesting sites at Farmington and Bear River Bays nearly disappear at low lake levels, threatening the high density and diversity of birds that rely on these zones (Wurtsbaugh et al. 2016). At the Salton Sea, a large breeding colony of Double-crested Cormorants (over 5,000 nests) was abandoned in 2013 when lowering of lake levels produced a land bridge to Mullet Island (Lynch et al. 2014).

Changing water levels have also indirectly affected salinity-controlled food webs by altering salt concentrations (Herbst et al. 2014). In the South Arm of Great Salt Lake, brine shrimp and their cysts comprise up to 95% of the Eared Grebe's diet (Belovsky et al. 2011). To meet daily energy needs and accumulate fat reserves for their southbound migration, Eared Grebes must consume an estimated 26,500-29,600 adult brine shrimp daily while staging at Great Salt Lake (Conover and Caudell 2009). At Mono Lake, brine shrimp are a major food source early in the year, but brine flies are preferred by June (Jehl 1988). Both increases and decreases in salinity can negatively impact brine shrimp and brine fly populations, which dominate when salinities range from 3-15% (Moore 2016). Invertebrate species richness declines with increasing salinity (see Warnock et al. 2002). Decreasing salinity allows freshwater species to invade, resulting in reduced brine shrimp abundances due to increased competition and predation. Salinity levels that rise too high reduce algal growth, leading to reduced brine shrimp survival, size, and nutrient content. Hypersaline waters can become too saline even for salinity-tolerant brine flies and shrimp (Wurtsbaugh and Berry 1990, Wurtsbaugh 1992, Grimm et al. 1997, Herbst 2014). At Lake Abert, sharp increases in salinity resulted in a massive die-off of alkali flies and brine shrimp in 2014 (Larson et al. 2016). Eared Grebes were absent from the lake that year, although in 2012 there were more than

40,000 present (Larson et al. 2016). Small numbers of other species, including American Avocet and Wilson's Phalarope, were present on the lake, demonstrating their extreme adaptability (Larson et al. 2016). Other birds may be less tolerant of changing conditions, including Red-necked Phalarope, which rely on brine flies and are incapable of surviving on brine shrimp alone (Rubega and Inouye 1994). Since brine flies are more vulnerable to changes in salinity than brine shrimp, risks are even higher for these species (Rubega and Inouye 1994).

Surface waters at many saline lakes have become toxic due to the accumulation of salts and metals that leach out of irrigated croplands and enter return flows (Lemly et al. 2000). At the Lahontan Wetlands, the combination of heightened salinity and contaminated agricultural runoff loaded with trace elements, including arsenic, mercury, and selenium, created toxic flows killing 7 million fish and 1,500 waterbirds at the mouth of the Carson River in the late 1980s (Lemly et al. 2000, Pringle 2000). These contaminated waters devastated the foraging base for the American White Pelican, and caused reproductive failure, with only a quarter of nests hatching (Lemly et al. 2000). Contamination has also affected Great Salt Lake, where increased mercury levels have been found in the livers of Eared Grebes and brine shrimp over the past few decades (Darnall and Miles 2009). Additionally, American Avocets at Great Salt Lake have been found to have elevated concentrations of selenium in their livers, and a negative relationship has been observed between selenium concentrations and body mass (Wurtsbaugh 2009). Selenium has also been a threat to birds at the Salton Sea, where increased concentrations of the metal in wastewater inflows were followed by massive die-offs of fish and birds in the 1980s (Hurlbert 2011). Other large die-off events have also occurred at the lake undiagnosed, including one in 1989 and another in 1992 that killed an estimated 150,000 Eared Grebes (Jehl and McKernan 2002).

Vegetation changes are also threatening birds at saline lakes and adjacent wetlands. At Great Salt Lake, non-native Phragmites, also known as common reed, more than doubled in percent cover between 1977 and 2004, increasing from 20% to 57% (Kulmatiski et al. 2010). Currently Phragmites covers almost 23,000 acres of wetland habitat at Great Salt Lake where it is associated with prolonged inundation, point sources for pollution, and moderate salinities (Long et al. 2017), and has been observed colonizing open mudflat areas (Hoven, unpublished data). Loss of habitat from the invasion of Phragmites raises conservation concerns for American Avocet, Black-necked Stilt, and Western Snowy Plover (Kulmatiski et al. 2010, Ellis et al. 2015). Expansion of saltcedar, discussed in detail in the previous section of the report, is also an issue for both the Salton Sea and Colorado River Delta, where it has colonized sites of freshwater inflow to the Salton Sea and unvegetated areas in the Colorado River Delta, reducing the availability of mudflat and wetland habitats.

Climate Change

The future of saline lakes is at risk due to the cumulative effects of present-day threats (e.g., reduced inflows, declining water quality, invasive species) and the future threat of climate change on the entire hydrological cycle (Jellison et al. 2008, Moore 2016). Climate change is predicted to further threaten saline lakes and the birds that depend on them by leading to increased temperatures and aridity, more frequent and severe droughts, and shifts in the timing, type, and amount of precipitation (Cook et al. 2004, Barnett et al. 2008). In the arid West, the impacts of climate change are already being felt: up to 60% of the observed hydrologic changes in the western U.S. between 1950 and 1999, including reduced river flow and snowpack, are the result of human-caused climate change (Barnett et al. 2008). Drought conditions covering more than half the contiguous U.S. in the early 2000s are a preview of future conditions that threaten the permanence and existence of many wetlands (Grimm et al. 1997, Cook et al. 2004). Drier conditions will exacerbate the effects of human modifications at saline lakes, with additional decreases in streamflow and groundwater recharge (Ficklin et al. 2013, Meixner et al. 2016). Across the western U.S., snowpack could decline by 60% in the next 30 years (Fyfe et al. 2017). At Great Salt Lake, expected declines in mountain snowpack will likely lead to lower average lake levels and increased average salinity unless winter precipitation increases (BRAC 2007). In the Mono Lake Basin, temperatures could increase by over 7°F with declines in precipitation by 3% over the next century, leading to an increase in annual evaporation by 0.4

inches and decreases in streamflow by 15% (Ficklin et al. 2013).

Many saline lakes are currently snowmelt-fed, but under a warmer climate more precipitation will come as rain, increasing the risk of flooding in the wet season and prolonged drying in the warm season (Grimm et al. 1997). Recent findings suggest that more precipitation falling as rain combined with earlier, slower snowmelts may actually reduce surface flows in snowmelt-dominated systems (Berghuijs et al. 2014, Barnhart et al. 2016). Warming temperatures will also advance peak snowmelt, threatening the availability of freshwater habitat during the breeding season when waterbirds and their chicks need it most (Hannam et al. 2003, Ficklin et al. 2013). Streamflow timing has already advanced by 1-4 weeks across the West since 1948, and future advances of over a month have been projected in the eastern drainages of the Sierra Nevada due to earlier snowmelt, reduced snowpack, and more precipitation as rain (Stewart et al. 2005, Costa-Cabral et al. 2013). Changes in the timing and amount of inflows will also alter salinity concentrations at saline lakes, disrupting food webs and the resources that migratory birds depend on (IWJV 2013).

Species themselves may also be inherently sensitive to climate change. Audubon characterized climate change sensitivity by predicting where climatic conditions currently occupied by each species are likely to be found in the future (Table 7, Langham et al. 2015). Six out of nine priority species are classified as climate endangered, meaning that projections suggest that climate in half of their current range by 2050 will no longer be representative of climates where the species is found today, even under the mildest scenarios of future warming. This assessment is based on the entire range of each species; vulnerability in the Intermountain West is likely higher due to the magnitude of projected changes in climate and the corresponding impacts on water availability at saline lakes.

Table 7. Climate sensitivity of priority saline lake species (Langham et al. 2015). Sensitivity status is defined by projected loss and gain of a species' climatically suitable range. Climate endangered species are projected to lose more than half of their current range by mid-century, with no net gain from potential range expansion. Climate threatened species are projected to lose more than half of their current range by the end of the century, with possible net gain from potential range expansion. Climate stable species are projected to lose less than half of their range by the end of the century.

Priority Species	Climate Sensitivity
Ruddy Duck	Stable
Eared Grebe	Endangered
American White Pelican	Endangered
White-faced Ibis	Endangered
American Avocet	Endangered
Snowy Plover	Threatened
Marbled Godwit	Endangered
Western Sandpiper	Stable
Wilson's Phalarope	Endangered

Knowledge Gaps

In the dynamic landscape of the Intermountain West, surprisingly little is known about long-term changes in bird populations, particularly for shorebirds and waterbirds. Given the importance of saline lakes for breeding and migration, it is important to establish credible baseline population estimates across this network of lakes so that we are prepared to monitor and detect the changes that may occur in the future and respond accordingly. In order to achieve these goals, we recommend directing further research towards the following areas:

- Coordinated, long-term monitoring for the purpose of estimating seasonal bird populations on all saline lakes of the Intermountain West. Monitoring will allow for increased understanding of how bird populations fluctuate over time and across lakes in response to changing environmental conditions, and is particularly needed for declining species.
- Long-term monitoring of water levels and salinity at all saline lakes correlated with bird count monitoring data.
- Accelerated deployment of technologies for understanding migratory connectivity and population turnover rates among saline lakes and other regions, including genetic approaches (Ruegg

et al. 2014), land-based approaches such as networks of Motus towers, and satellite-based approaches like PeliTrack and the International Cooperation for Animal Research Using Space (ICARUS, Wikelski et al. 2007).

- Modelling of projected changes in the carrying capacity across saline lakes in the Intermountain West for bird populations. Declining inflows and corresponding loss of habitat and food resources may decrease the overall carrying capacity of the network (as in Iwamura et al. 2013).
- Detailed studies of hydrological budgets for all saline lakes (e.g., Larson et al. 2016, Moore 2016) in order to understand the relative contribution of diversions to lake level declines.
- Baseline estimates of wetland, mudflat, playa, and open water habitat extents that can be updated regularly utilizing remotely sensed imagery.
- Assessments of wetland habitats and their rates of change due to decreased inflows or invasive species. Management plans that mitigate the effects of reduced water supply and restore native vegetation where possible (e.g., Salton Sea, Jones et al. 2016).
- Improved estimates of future lake levels and salinity at saline lakes accompanying different climate change and water use scenarios. Projections should consider future changes in temperature, evaporation, precipitation, and water-diversions.
- Further study into the effects of declining water quality on avian reproduction (e.g. selenium) and survival (e.g. botulism).
- Further study into other factors impacting declines of priority species, such as predation and habitat loss.

Conclusions and Future Strategy

Saline lakes are vital to sustaining migrating and breeding waterbirds, shorebirds, and waterfowl up and down the Central and Pacific Flyways. These lakes and associated wetlands, mudflats, and playas provide abundant food, such as brine flies and shrimp, and relatively undisturbed habitat that enable birds to fuel up for their migrations. These habitats and concentrated food resources are irreplaceable: no other ecosystem in the Intermountain West can meet these birds' unique requirements. As an interconnected network, these lakes support large portions of priority species during migration and breeding.

Saline lake levels have dramatically declined, reducing the extent of open water, wetlands, playa and mudflat habitats and food resources available to migratory birds. Saline lakes are globally threatened both by reduced water volume due to draining, diversion of inflows, and lake and groundwater extraction, and by declining water quality, from the accumulation of salts, nutrients, metals, and pesticides. With lower water levels, salinities at many large terminal lakes in the Intermountain West have increased dramatically in recent years, altering salinity-controlled food webs and reducing superabundant invertebrates consumed by migrating and resident waterbirds. Declining inflows have also reduced nesting and foraging habitat, exposing birds to increased predation, contamination, and disease. Since bird populations move across saline lakes throughout the year, these places function as an interconnected network. Declines at one site can be absorbed at another, but network-wide decline threatens the integrity of the entire system, putting millions of birds at risk, such as Eared Grebe, Wilson's Phalarope, and American Avocet whose global populations depend on these lakes. Shorebird populations are already in decline, and while the status of many other waterbirds are either unknown or believed to be stable, the future risks of inaction are high. The relatively wet winter of 2016-17 has increased inflows for the present, but recent trends and long-term projections of climate change suggest that climate-induced declines in freshwater flows will combine with human diversions to negatively impact bird populations at saline lakes throughout the Intermountain West.

Given the irreplaceability of saline lakes, Audubon will be working with partners to establish stronger baseline abundance and population trend estimates for birds across the network of saline lakes, as well as to better understand the relative contribution of diversions to lake level declines. Future work will include detailing hydrologic budgets for priority saline lakes, including projections of lake levels and salinity under climate change. This work will help define the overall vulnerability of the system to the long-term threat of climate change.

SOLUTIONS THAT WORK: BIRDS RETURN TO A REVITALIZED LAKE

Owens Lake by Greg Balzer / Flickr CC (BY 2.0)

Audubon is working with partners to use science-based planning to help direct relatively small amounts of water to recreate an array of distinct bird habitats in California's saline Owens Lake. A stakeholder group, spearheaded by Audubon, and consisting of other conservation groups, Native American tribes, industry, state and federal wildlife and air quality agencies, and the Los Angeles Department of Water and Power, worked together to complete a Master Plan in 2014 that sets a course to maintain Owens Lake for wildlife habitat, while controlling dust and conserving water. Re-watering of Owens Lake has been a resounding success: in a recent spring count, 115,000 birds – including 20 different species – were tallied. Just as farmers use drip irrigation to grow more crops with less water, Audubon is identifying ways to more precisely direct water resources in ways that better support birds.

Many existing policies protecting saline lakes are actually geared towards protecting their associated freshwater wetlands for waterfowl game species (e.g., North American Wetlands Conservation Fund, Brown et al. 2002) or more broadly towards recreation (e.g., Land and Water Conservation Fund, Zinn 1999). More recently, concerns about contaminated dust from drying lakebeds impacting air quality has resulted in funds for habitat management and dust mitigation (often through flooding of desiccated areas). These air quality concerns have led to the creation of thousands of acres of restored habitat in Owens Lake (LADWP 2013) and a new management plan for the Salton Sea (Jones et al. 2016).

Even in the face of multiple threats to water availability and quality, we can preserve habitat for shorebirds, waterfowl, and waterbirds, and secure important human health benefits as well. In its Saline Lakes Program, Audubon will deepen its long-standing commitment to protecting habitats at Great Salt Lake, a critical place for many birds under threat, and a site where we can build on the work of dedicated staff in Utah. We also continue to work to secure healthy habitat for a future Salton Sea. In the western Great Basin, Audubon will identify and act on opportunities to secure water to maintain or enhance bird habitats at places like Lake Abert in Oregon and the Lahontan Valley in Nevada.

We will build on proven solutions to extend our efforts to other critical saline lakes across the West. Audubon has successfully advocated for or actively restored habitat and essential food sources for birds by delivering small amounts of water at the right times and places. Audubon will use lessons learned at Owens Lake, where Audubon California and Eastern Sierra Audubon Society initiated a Conservation Plan in partnership with stakeholders that concurrently conserves precious water, controls dust, and maintains habitat. We have also seen success at Great Salt Lake, where the dry riverbed at the Gillmor Sanctuary has been restored as productive bird habitat. Additionally, working with partners, we have advanced public policy initiatives, water efficiency measures, and pioneered market-based innovation to secure balanced water solutions for birds and people.

FINAL CONCLUSIONS AND RECOMMENDATIONS

Cooperative efforts to maintain and restore river systems, saline lakes and associated wetland habitats in the arid West will be necessary to avoid losing millions of birds. Audubon's top recommendations to protect the sites that are most significant to the future of these priority bird species and to address the threats to water and birds in the arid West include:

- Identify and support balanced solutions and water policies at the local, state, and federal level that avoid depleting water supplies for rivers, lakes and wetlands, and associated habitats
- Mobilize the Audubon network on behalf of creative, balanced water solutions and policies
- Increase public and private investment in water conservation, habitat restoration, and research
- Leverage our science to inform and help secure voluntary water sharing agreements including market-based solutions and flexible water management practices
- Support development and implementation of management plans that factor in habitat needs and include restoration of native vegetation
- Foster greater dialogue and action to reduce global climate change and its impacts on water availability
- Advance scientific understanding of bird populations and habitat linkages across western landscapes through additional research, field study, and monitoring
- Use climate change and connectivity modeling to prioritize conservation and restoration

Current conservation, restoration, and stewardship actions are attempting to stabilize regional populations, but proposed diversions and future threats are serious. Climate change, in particular, merits Audubon's continued advocacy. Audubon's Birds and Climate Change Report, published in 2014, confirmed that climate change threatens North American birds. In the arid West, the cumulative effects of climate change and water development are potentially devastating to birds.

There's no doubt, the challenges we face on the Colorado River and across saline lakes are significant. However, this doesn't mean there isn't enough water to go around. There is. We have to share our water resources to sustain economic growth, a vibrant agricultural economy, and healthy rivers and lakes. We need a new phase of collaboration, innovation, and flexibility when it comes to how we use and manage our water. Solving these water challenges will require reshaping water management so that the people, birds, and wildlife of the arid West can thrive together.

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