National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Tumacácori National Historical Park

Natural Resource Condition Assessment

Natural Resource Report NPS/SODN/NRR—2019/1965

ON THE COVER

View of Tumacácori National Historical Park. Photo Credit: © Lauren Hillquist.

Tumacácori National Historical Park

Natural Resource Condition Assessment

Natural Resource Report NPS/SODN/NRR—2019/1965

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August 2019

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Baril, L., K. Struthers, A. Hubbard, A. Mateljak, D. Angell, and M. Brunson. 2019. Tumacácori National Historical Park: Natural resource condition assessment. Natural Resource Report NPS/SODN/NRR—2019/1965. National Park Service, Fort Collins, Colorado.

NPS 311/156590, August 2019

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program, administered by the National Park Service's (NPS) Water Resources Division, provides a multidisciplinary synthesis of existing scientific data and knowledge about current conditions of important national park natural resources through the development of a park-specific report. The NRCA process for Tumacácori National Historical Park (NHP) was initiated in 2010 as a collaborative effort between the national historical park staff, the NPS Sonoran Desert Inventory and Monitoring Network (SODN) staff, NPS Intermountain Region, and the Sonoran Institute. Ten focal resources were selected for condition assessment reporting, and in 2017, Utah State University was added as a partner to complete the NHP's NRCA report.

The national historical park's 10 natural resources evaluated for current conditions were grouped into three broad categories: air and climate (i.e., air quality), water (i.e., hydrology and water quality), and biological integrity (i.e., vegetation and wildlife topics). The majority of resources were found to be of moderate concern except for the wildlife resources— birds and mammals,— which are good. Like many national parks throughout the United States, the resource conditions at Tumacácori NHP are vulnerable to stressors far beyond its borders, such as warming temperatures, variable and intense precipitation events, and surrounding land use changes. These landscape-scale drivers underscore the need for partnerships that transcend political boundaries and instead focus on ecological boundaries to achieve shared conservation goals, thereby improving resource conditions.

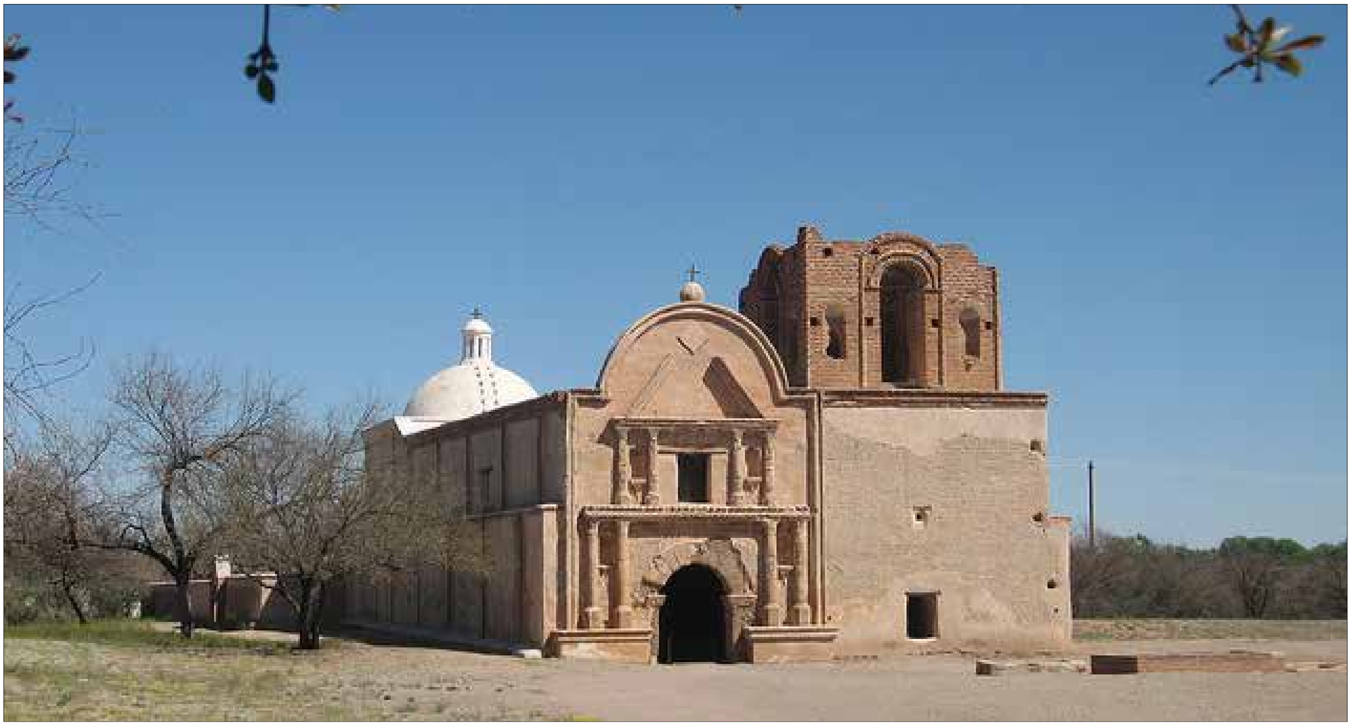
Acknowledgements

We thank Tumacácori NHP's Chief of Resource Management and Park Archeologist, Roger Dorr, and Biological Science Technician, Drew Jackson, for providing data and reports. We also are indebted to the NPS Sonoran Desert Inventory and Monitoring Network (SODN) staff, Andy Hubbard, Kristen Bonebrake, Sarah Studd, Evan Gwilliam, and Alice Wondrak Biel, and former staff, Debbie Angell and Anna Mateljak, for their assistance in gathering data; establishing indicators, measures, and reference conditions; and for reviewing drafts of the assessments and chapters. For some of the resources evaluated, an initial condition assessment draft was provided.

SODN's inventory and monitoring data informed current conditions for several of the park's water, wildlife, and vegetation topics. Kara Raymond, hydrologist with the NPS Southern Arizona Office, provided expert reviews and information for most assessment topics.

Phyllis Pineda Bovin, NPS Intermountain Region Office NRCA Coordinator, assisted with overall project facilitation and served as subject matter expert review manager. Jeff Albright, NPS NRCA Program Coordinator, provided programmatic guidance.

And finally, to all of the additional reviewers and contributors, who are listed in Appendix A, we thank you. Your contributions have increased the value of Tumacácori NHP's NRCA report.



Ruins of the Franciscan church at Mission San José de Tumacácori. Photo Credit: NPS SODN.

NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement, not replace, traditional issue- and threat-based resource assessments. As distinguishing characteristics, all NRCAs

- Are multi-disciplinary in scope; [1]
- Employ hierarchical indicator frameworks; [2]
- Identify or develop reference conditions/values for comparison against current conditions; [3]
- Emphasize spatial evaluation of conditions and Geographic Information System (GIS) products;[4]
- Summarize key findings by park areas; and [5]
- Follow national NRCA guidelines and standards for study design and reporting products.

[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures - conditions for indicators - condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs. Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions, but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

An NRCA is intended to provide useful science-based information products, such as the bats monitoring at Tumacácori NHP in support of all levels of park planning. Photo Credit: NPS.

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What a NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website at http://www.nature.nps.gov/water/nrca/.

[6] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

Flowering penstemon in foreground with Mission San José de Tumacácori church in background. Photo Credit: NPS.

Introduction and Resource Setting

Introduction

Enabling Legislation/Executive Orders

The Santa Cruz River Valley in southern Arizona has been inhabited by humans for thousands of years, with settlement centered on the river. By the late 17th century when Europeans first entered the area and established cattle ranches, native Piman tribes had been living in the valley and farming the floodplain for more than 200 years. Father Eusebio Francisco Kino and other Jesuit missionaries founded more than 20 missions in native settlements in the Pimería Alta in the 17th and 18th centuries before their expulsion in 1767, when the Franciscans assumed administration of the system (Figure 1). By the mid-19th century, the missionaries had left the area, partly due to the intensification of Apache raids from the north, and the mission structures began to deteriorate or were put to other uses. In order to preserve these historic ruins, three sites were set aside as part of the National Park system.

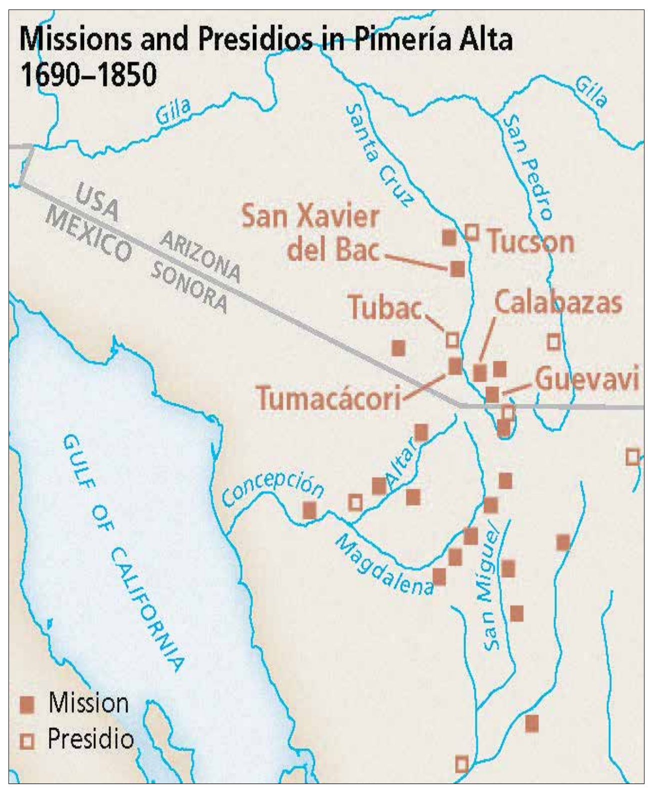


Figure 1. The Missions and Presidios in Pimería Alta, including the three units comprising Tumacácori NHP. Figure Credit: NPS.

On September 15, 1908, under the authority of the Antiquities Act of 1906, Presidential Proclamation No. 821 (35 Stat. 2205) established an area of 3.7 ha (9.11 ac) as Tumacácori National Monument to preserve “. . . the Tumacácori Mission, an ancient

Spanish ruin, which is one of the oldest mission ruins in the southwest . . .". On March 28, 1958, Presidential Proclamation No. 3228 (72 Stat. c30) added 0.06 ha (0.15 ac) that included the ruins of a lime kiln that was part of the original mission establishment to the park. In March 1978, the authorized boundary was again revised by the addition of 2.6 ha (6.37 ac) and removal of 0.05 ha (0.13 ac) under the authority of the National Parks and Recreation Act. On August 6, 1990, an Act of Congress (Public Law 101-344 [H.R. 2843]) combined the existing park with two additional nearby Spanish colonial sites (Calabazas and Guevavi) and changed the designation from "National Monument" to "National Historical Park." On August 21, 2002, another Act of Congress (Public Law 107-218 [116 Stat. 1328]) authorized the addition of 125 ha (310 ac) surrounding the Tumacácori mission "to protect and interpret the resources associated with the Tumacácori Mission" and "to enhance the visitor experience... by developing access to these associated mission resources." Today Tumacácori National Historical Park (hereafter referred to as Tumacácori NHP) encompasses 145 ha (360 ac; NPS 2014a) and is the only unit in the National Park Service (NPS) that displays an entire, original institutionalized Spanish mission landscape including a cabecera, visita, ranchería, and ganadera (NPS 2014a).

The NHP comprises three sites – all of which contain some of the best remaining examples of the architectural styles of the Spanish Mission Period – the Tumacácori unit, the Guevavi unit, and the Calabazas unit (hereafter referred to as Tumacácori, Guevavi, and Calabazas).

The Tumacácori unit (133 ha; 330 ac) preserves Mission San José de Tumacácori, a nearly complete mission complex. The oldest mission site in Arizona, it was founded as a visita in January 1691 by Father Kino on the east side of the Santa Cruz River (NPS 2009). Subsequently moved to a more favorable site on the west side of the river (Drake et al. 2009), the mission later became the cabecera under the Franciscans who began building the church in 1800. Abandoned in 1848, the church building endures as "an excellent example of original 1800s Franciscan mission architecture with a number of distinctive, well preserved features" (NPS 2014a). The acreage added in 2002 includes a 1.6-km (1-mi) stretch of the Santa Cruz River and its adjacent riparian corridor, the mission orchard and acequia, and farmlands (NPS 2014a).

The Guevavi unit (3 ha; 8 ac) preserves a second mission site also established in 1691, one day after Tumacácori. The ruins of Los Santos Ángelos de Guevavi are the remains of the first Jesuit mission built in what is now Arizona. Construction of the church began in 1701 and was completed in 1732. Following major disruptions to life at the mission, including the Pima Revolt of 1751, disease, removal of the Jesuits, and Apache raids, the cabecera was relocated to Tumacácori in 1771. The Guevavi site was finally abandoned in 1775 (NPS 2008). Today Guevavi is "a relatively pristine archeological site"; and although eroded nearly to the ground (NPS 1997), it is the only preserved earthen Jesuit cabecera in the United States (NPS 2014a).

The Calabazas unit (9 ha; 22 ac) preserves the ruins of San Cayetano de Calabazas, established in 1756, the only known remaining standing Spanish colonial visita in the national park system (NPS 2014a). This site is somewhat better preserved than Guevavi because it was reoccupied and modified several times between its abandonment by the church and the early 20th century (NPS 1997). These ruins represent a history of diverse and extensive uses as a mission-period ranchería, visita, ganadera, Mexican governor's residence, U.S. cavalry camp, customs house, and finally a post office. Calabazas was totally abandoned by 1878 (NPS 2014a).

The natural resources (e.g., water, riparian habitat, plants, animals, soils, etc.) preserved by Tumacácori NHP were important to the settlement of the Santa Cruz Valley, and the park is dedicated to maintaining the landscapes that attracted and sustained the historic native peoples and European settlers before, during, and after the mission period. Protecting and preserving the ecological processes that created the cultural setting are essential to the interpretation of the relationship between these residents and their natural environment.

Geographic Setting

Tumacácori NHP is located along the Santa Cruz River in the upper Santa Cruz River Valley in southern Arizona's Santa Cruz County. The park is approximately 29 km (18 mi) north of the town of Nogales, a major port of entry along the U.S.-Mexico border, and 69 km (43 mi) south of Tucson, the major urban area in southeastern Arizona (Figure 2). The altitude of the three units ranges from 994 to 1,097 m

Figure 2. Tumacácori NHP is situated along the Santa Cruz River, approximately 69 km (43 mi) south of Tucson, Arizona. Figure Credit: NPS.

(3,261 to 3,599 ft; Mau-Crimmins et al. 2005). The Santa Rita, San Cayetano, and Patagonia Mountains lie east of the park, the Tumacácori and Atascosa Mountains are to the west, and the Pajarito Mountains are to the southwest (Powell et al. 2005). Tumacácori is primarily adjacent to private land, much of it used for irrigated agriculture and cattle ranching. Guevavi, 23 km (14 mi) south-southeast of Tumacácori, is surrounded on four sides by City of Nogales land purchased for water rights, and bordered by the Santa Cruz River to the southwest (Mau-Crimmins et al. 2005). Calabazas, 15 km (9 mi) south-southeast of Tumacácori, is bordered by the 22,257 ha (55,000 ac) Rio Rico subdivision on three sides (NPS 1997) and by the Santa Cruz River on the west side. Just west of the river is the Nogales International Wastewater Treatment Plant (NIWTP; Mau-Crimmins et al. 2005).

In general, the Southwest, especially Arizona, is one of the fastest growing regions in the United States. The NHP is located in Santa Cruz County, with a population of 46,212 in 2017. This represents a population decrease from 2010-2017 by -2.6% (U.S. Census Bureau 2018), which hasn't followed the typical population growth pattern occurring in Arizona.

Tumacácori NHP is located within the semidesert climatic zone of southern Arizona. This has a distinct bimodal precipitation regime characterized by violent summer thunderstorms from the North American monsoon originating from the Gulf of Mexico and low-intensity Pacific frontal precipitation in the winter months (Mau-Crimmins et al. 2005). Winds are primarily from the southwest. The long summers (April-October) are hot, with maximum temperatures averaging greater than 32° C (90° F) from May to September and greater than 38° C (100° F) in July.

The NPS Sonoran Desert Inventory and Monitoring Network (SODN) (NPS SODN 2018a) reports the most recent precipitation results for Tumacácori NHP as follows:

> In WY2017, overall annual precipitation was 68% of normal for Tumacácori National Historical Park (11.26" vs 16.56"). Precipitation in December and January was greater than normal. October, November, February, and March were extremely dry. The monsoon was strong for three weeks in July, but tapered off quickly, a pattern seen throughout the Sonoran Desert. Air temperatures were generally 2–8°F warmer than normal, with the exception of the mean maximum temperature in January. The extended regional drought that began in 2000 continued through WY2017.

Visitation Statistics

Because Calabazas and Guevavi are only open to the public on special reserved tours during the winter, the numbers presented in this section represent visitation for Tumacácori only. Statistics (NPS Public Use Statistics Office 2019) show that visitation at the park was fewer than 20,000 visitors annually between 1920 and 1946, ranging from a low of 4,300 in 1920 to a high of 19,176 in 1946 (Figure 3). Following World War II, visitation generally increased, reaching a peak of 80,300 visitors in 1976. Visitation then began declining, dropping 22% in 1979 when Interstate 19, just west of the park, was completed (NPS 1997). From 1979 to 2000, the number of visitors remained relatively stable at just under 60,000 per year. Visitation has generally declined since 2000, reaching a low of 31,433 in 2013 (NPS Public Use Statistics Office 2019). Monthly visitation is highly variable depending upon the season, but the highest visitation occurs in December when thousands attend the annual La Fiesta de Tumacácori

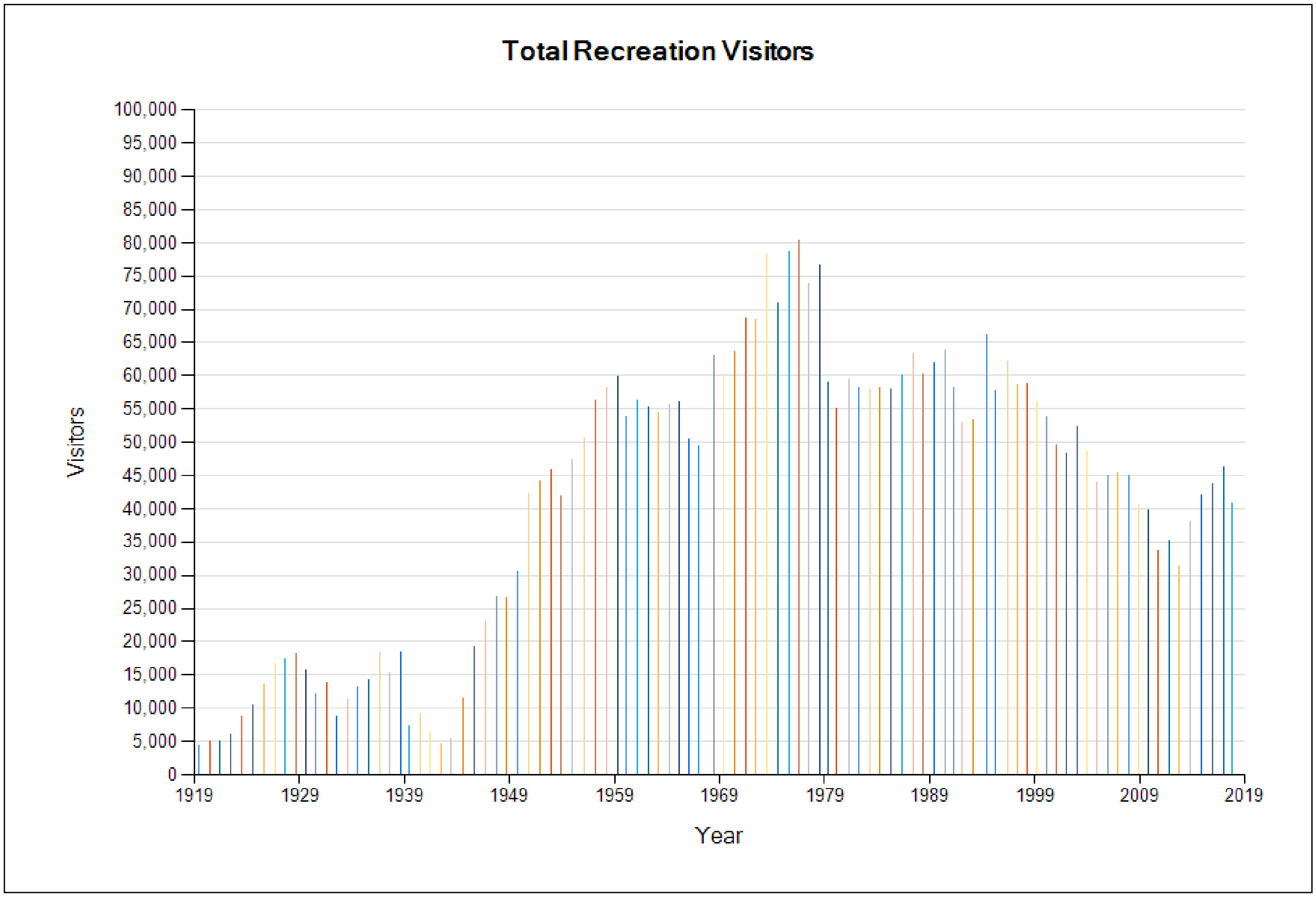


Figure 3. Total number of annual visitors to Tumacácori NHP from 1920-2018. Figure Credit: NPS Public Use Statistics Office 2019.

during the first weekend of the month and Luminarias on December 24.

Natural Resources

Ecological Units and Watersheds

Tumacácori NHP is within the Apache Highlands Ecoregion (as defined by The Nature Conservancy), which spans 12 million ha (30 million ac) in the states of Arizona and New Mexico in the U.S. and the states of Sonora and Chihuahua in Mexico. It is bounded by the Mogollon Rim to the north, the Sonoran and Mohave Desert Ecoregions to the west, the Sierra Madre Occidental to the south, and the Chihuahuan Desert Ecoregion to the east. The region covers 25% of the Arizona and contains 32% of the state's perennial stream systems, which are crucial to the sustainability of Arizona's biodiversity and human habitation. The Apache Highlands Ecoregion is best known for its mountainous "sky islands" alternating with desert basins (Marshall et al. 2004).

During the development of Arizona's comprehensive wildlife conservation strategy, the Arizona Game and Fish Department divided the Apache Highlands Ecoregion into north and south regions. Tumacácori NHP lies within the Apache Highlands South Ecoregion, which encompasses 3.4 million ha (8.5 million ac) in Arizona with 20 sky island mountain ranges and desert basins. Elevations range from approximately 670 to 3,050 m (2,200 to 10,017 ft), averaging approximately 1,320 m (4,340 ft).

Due to the wide range in elevations and its position between the Neotropic influence of the Sierra Madre Mountains to the south and the Nearctic influence of the Rocky Mountains to the north, the Apache Highlands South Ecoregion contains a striking variety of habitat types and associated wildlife. Vegetation at the upper elevations is dominated by pine-oak woodlands and mixed conifer forests; the desert basins are comprised of grassland and desertscrub vegetation (Marshall et al. 2004). The region includes the San Pedro River, portions of the Santa Cruz and Gila

Rivers, Sonoita and Cienega Creeks, and ephemeral wetlands including the Willcox Playa and Whitewater Draw. A disproportionately high number of wildlife species are found in the riparian habitat associated with these aquatic systems (AGFD 2006).

Cattle ranching and small areas of agriculture where water was available were the primary historic uses in this ecoregion. Ranching remains a dominant land use despite increasing human presence and associated development that has led to habitat fragmentation (AGFD 2006). The Bureau of Land Management or the U.S. Forest Service currently manages all of the major mountain ranges in the U.S. portion of the region, protecting them from permanent development. The grassland basins, however, are primarily privately- or state-owned lands that have experienced a rapid change with major encroachment of shrubs, some of it irreversible (Marshall et al. 2004). Border-related issues – illegal immigrants, drug smuggling, and law enforcement activities – result in significant pressure on the ecoregion (AGFD 2006).

Tumacácori NHP is within the Santa Cruz watershed (Figure 4), which covers 20,720 km2 (8,000 mi2), or 10%, of the state of Arizona. Surface water sources include Sonoita, Cienega, and Harshaw Creeks; Davidson and Three "R" Canyons; Alum Gulch; Arivaca, Parker, and Lakeside Lakes; and the 362-km (225-mi) Santa Cruz River (USEPA 2017a). From its headwaters at an altitude of 1,524 m (5,000 ft) in the San Rafael Valley of southeastern Arizona (Armbrust and Brusca 2005), the Santa Cruz flows southward into Mexico, curves northward and re-enters the U.S. just east of Nogales, then continues to its confluence with the Gila River.

Resource Descriptions

Tumacácori NHP is located within the Basin and Range geological province, which formed when the earth's crust was pulled apart by tectonic forces, is characterized by north-south trending fault-bounded mountain ranges alternating with nearly flat sediment-filled desert basins (Mau-Crimmins et al. 2005, Graham 2011). The mountains to the east of the park are Precambrian to Miocene igneous, metamorphic, volcanic, and sedimentary rocks; those to the west of the park are primarily Tertiary volcanic rocks except for a Jurassic granitic pluton at the northern end of the Tumacácori Mountains; and those to the southwest are Cretaceous volcanics (Powell et al. 2005).

According to Graham (2011), all three units are composed chiefly of unconsolidated sediments eroded from these mountains. The surface geology at Tumacácori consists of Holocene floodplain, terrace, and modern river channel deposits washed down from the adjacent highlands. Sedimentary and igneous rocks from the Tertiary and Mesozoic Periods border Calabazas and Guevavi. Calabazas also contains exposed portions of the "Salero Formation, a unit of sandstone, conglomerate, and volcanic material (tuff) deposited approximately 75 to 70 million years ago during the late Cretaceous Period" (Drewes 1968 as cited in Graham 2011). Granitic quartz monzonite, created during the Jurassic Period, forms the southern border of Guevavi and is the oldest type of rock in the park. The Santa Cruz River riparian area is composed of modern floodplain and river sediments.

Soils at Tumacácori NHP are those typically found on the floodplains, alluvial fans, and valley slopes of the area; they are deep and well drained, with a high water holding capacity. They are productive agriculturally; have few limitations on their use; and are suitable for

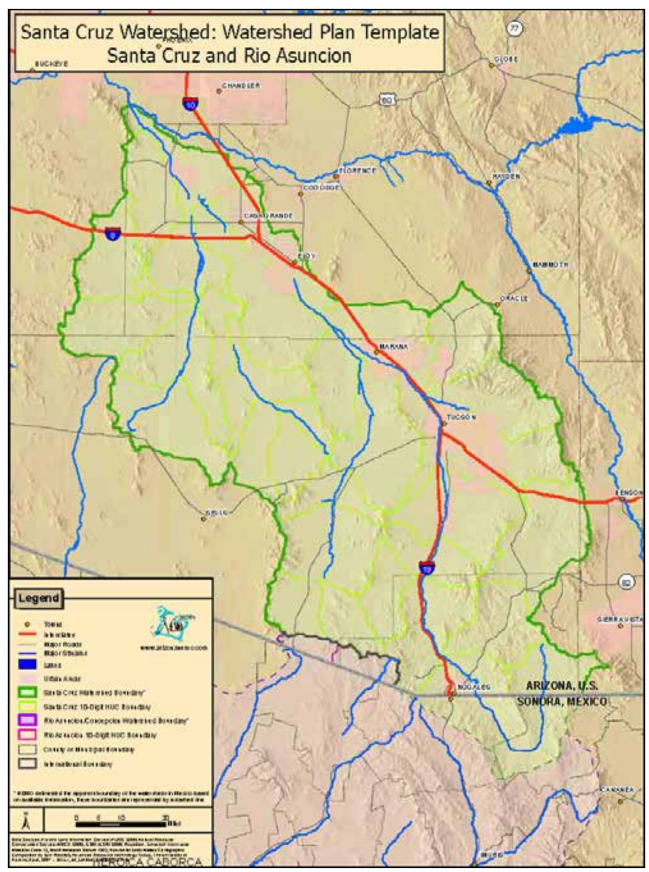


Figure 4. Tumacácori NHP is within the Santa Cruz watershed. Figure Credit: USEPA 2017a.

residential and industrial building, wildlife habitat, and recreational uses (NPS 1997).

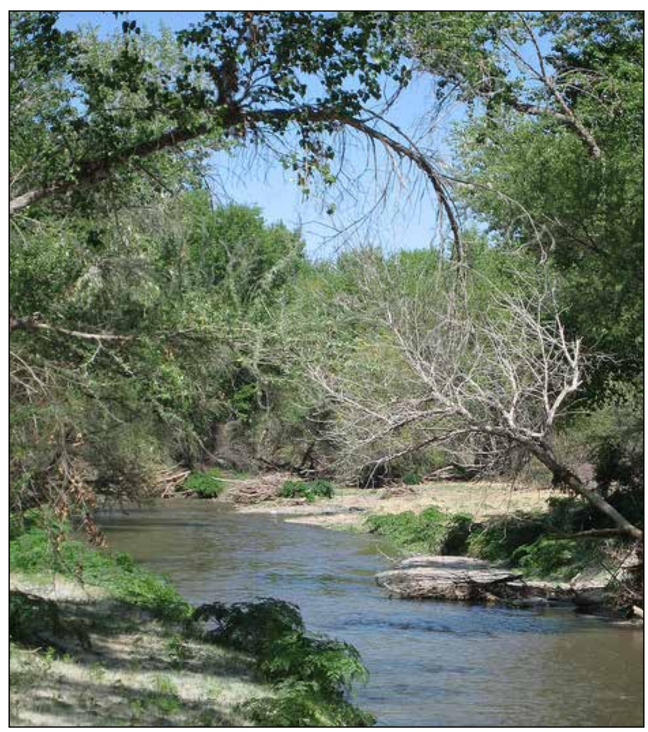
Tumacácori NHP is designated as a Class II airshed. Visibility trend data are collected at the Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring station SAGU1, AZ at Saguaro National Park. Most of the industry in Nogales is free of serious air pollution problems, but threats to air quality may increase as the Rio Rico subdivision continues to grow (Mau-Crimmins et al. 2005).

Along the Santa Cruz River north of Nogales to Amado, Arizona, basin-fill sediments form three aquifer units – the Nogales Formation, the Older Alluvium, and the Younger Alluvium, in ascending order (Mau-Crimmins et al. 2005). The Nogales Formation is approximately 1,524 m (5,000 ft) thick (Simons 1974 as cited in ADWR 1999), consisting of well-consolidated conglomerates with interbedded volcanic tufts. It is not widely developed as a water source because it has poor water bearing characteristics; average well yields are <113 liters per minute (30 gpm; ADWR 1999). Not generally considered an aquifer, the Nogales Formation may better be described as hydrologic bedrock (Mau-Crimmins et al. 2005). The Older Alluvium ranges from a thickness of approximately 1 m (a few feet) along the mountain ranges to ≥305 m (1,000 ft) in the north-central portion of the Santa Cruz Active Management Area (AMA). It is composed of "locally stratified lenses of boulders, gravel, sand, silt, and clays with cemented zones or caliche" (Anderson 1956, Schwalen and Shaw 1957, Putman et al. 1983, all as cited in ADWR 1999). Although the Older Alluvium is the most extensive unit within the AMA and stores a large volume of water, transmissivity is generally low and well yields are typically small (ADWR 1999). The Younger Alluvium (also referred to as stream or floodplain alluvium) is found along the Santa Cruz River and some of its larger tributaries. It is 12-46 m (40-150 ft) deep, with the thickness generally increasing in a northerly direction following the river's path, and is comprised of unconsolidated sands, gravels, and boulders, usually more coarse grained than the Older Alluvium (Schwalen and Shaw 1957 as cited in ADWR 1999). It is the most productive aquifer in the region due to its large hydraulic conductivity, with some wells yielding >3,785 liters per minute (1,000 gpm), and is the source of most of the water withdrawn from wells in the Santa Cruz AMA (ADWR 1999).

The Santa Cruz River is the major source of recharge for the younger alluvium aquifer and is an important corridor that allows species to travel between natural core areas (Beier et al. 2006). Between Josephine Canyon and Amado, including Tumacácori NHP, the width of the floodplain averages about 2.5 km (1.5 mi; Mau-Crimmins et al. 2005). Factors contributing to the increased frequency of flooding on the river since the mid-1970s include increased runoff following summer storms as a result of the replacement of natural ground cover by developments (e.g., paved roads, residential development, and parking lots) and overgrazing by cattle on surrounding lands (NPS 1997).

Vegetation at Tumacácori NHP consists of cottonwood-willow riparian forest and woodland lining the Santa Cruz River channel, velvet mesquite bosque (forest) and woodland on the low terraces bordering the channel, with a transition to savanna, semidesert grassland, and desert (mesquite) scrub on the uplands away from the river (Drake et al. 2009).

In the riparian areas at Tumacácori, Fremont's cottonwood (*Populus fremontii*), Goodding's willow (*Salix gooddingii*), and Arizona walnut (*Juglans major*) form dense, structurally diverse stands. Velvet mesquite (*Prosopis velutina*), netleaf hackberry (*Celtis laevigata var. reticulata*), and Mexican elderberry (*Sambucus nigra* spp. *canadensis*) are common in the



Santa Cruz River. Photo Credit: NPS.

bosque and woodland. Velvet mesquite, foothills palo verde (*Parkinsonia microphylla*), acacia (*Acacia* spp.), wolfberry (*Lycium* spp.), greythorn (*Ziziphus* spp.), perennial short- and mid-grasses and forbs, annual grasses and forbs, and geophytes are common in the uplands (Mau-Crimmins et al. 2005, Powell et al. 2005).

Grass communities throughout the park range from mixed grama (*Bouteloua* spp.) grasses to limited dominance by big sacaton (*Sporobolus wrightii*), but they are notably dominated by disturbance-tolerant species, such as carelessweed (*Amaranthus palmeri*) and non-native bermudagrass (*Cynodon dactylon*; Drake et al. 2009). Calabazas and Guevavi are dominated by velvet mesquite, desert scrub, and semidesert grassland (Mau-Crimmins et al. 2005), but the riparian zone at Guevavi is suspected to be wetland based on the existing vegetation (NPS 1997).

The variety of aquatic and terrestrial habitats in Tumacácori NHP supports a diverse array of wildlife species. The mesquite bosques and riparian forests along the Santa Cruz River are especially important because they provide suitable habitat for many birds and other animals that could not otherwise live in the area. Terrestrial species include birds, large and small mammals, reptiles, and insects. Aquatic species include fish, amphibians, and insects.

In total, there may be as many as 211 species for the NHP of which 182 have been confirmed. This includes four non-native species (Eurasian collared-dove (*Streptopelia decaocto*), European starling (*Sturnus vulgaris*), rock pigeon (*Columba livia*), and house sparrow (*Passer domesticus*)). The most common species are representative of riparian communities in the region. Fourteen of 43 potential species of conservation concern (33%) are confirmed for the park.

To date, a total of 18 small mammals, 20 medium- to large-sized mammals, and 10 bat species have been confirmed at the park. A noteworthy mention is that out of five SODN parks that participated in the network's vertebrate and non-vascular plant inventory, Tumacácori's Calabazas unit contained the highest small mammal species richness (Powell et al. 2002). Park staff, along with bat researcher Karen Krebbs, periodically monitor for the presence of bats, both by netting and acoustically recording.

Powell et al. (2005) recorded seven amphibian and 17 reptiles species for a total of 24 species. Only one non-native species, American bullfrog (*Lithobates catesbeianus*), was observed during the Powell et al. (2005) survey effort. Unfortunately, it was the fifth most frequently observed species (*n*=23) but is only found in the Tumacácori unit (Powell et al. 2005).

Of the 36 species of fish native to Arizona, four have been reported at Tumacácori NHP, all of which are considered species of conservation concern by the Arizona Department of Game and Fish (AGFD). This includes the federally endangered Gila topminnow (*Poeciliopsis occidentalis*) (AGFD 2013, USFWS 2017). In addition, four non-native species have been reported in park waters for a total of eight fish species.

Armbrust and Brusca (2005) conducted a thorough inventory of aquatic macroinvertebrates in the Santa Cruz River and Tumacácori Channel, recording 139 aquatic taxa in 17 orders and representing 10 classes. Insecta (insects) was the dominant class, comprising 79% of all taxa found; within this class Diptera (true flies) were dominant, and the Chironomidae (non-biting midges) family accounted for at least 19% of all insect taxa. The second most diverse group of insects with 27 genera was Coleoptera (beetles).

Resource Issues Overview

Centuries of livestock grazing, conversion of land to agricultural uses, and fluctuating surface and groundwater profiles have substantially altered native vegetation and wildlife in the Santa Cruz River Valley (Drake et al. 2009). Southwestern cottonwood-willow and mesquite bosque ecosystems, in particular, have

Broad-billed hummingbird. Photo Credit: NPS.

been heavily impacted (Drake et al. 2009). Human activities and disturbance can affect the availability of water and nutrients, which in turn affects the plant and animal communities. For example, the Santa Cruz River has been seriously impacted by water diversion, groundwater pumping, livestock grazing, land clearing and development, the elimination of native species such as the beaver (*Castor canadensis*), and the introduction of non-native animals and plants such as the American bullfrog, and tamarisk (*Tamarix* spp). Grazing has also altered the area's vegetation, which in turn has altered wildlife populations through habitat modification and competition for resources.

Resource management concerns expressed at the scoping session for vital signs monitoring at Tumacácori NHP included: 1) adjacent land use (residential and non-residential), 2) altered fire regimes, 3) altered wildlife habitat use/fragmentation, 4) border impacts, 5), non-native flora and fauna, 6) recreation impacts, 7) threatened and endangered species issues, 8) trash, 9) trespass/poaching, 10) viewscapes, and 11) water quality and quantity (Mau-Crimmins et al. 2005). Additionally, resource impacts from climate change will likely include range shifts for plants, changes in phenology and species density, greater risk of fires, spread of non-native species, increased frequency and severity of droughts, decreased stream flows, and increases in flooding events (Garfin et al. 2014).

Additional details pertaining to these and other resource threats, concerns, and data gaps can be found in each Chapter 4 condition assessment and in Chapter 5 of this report.

Resource Stewardship

Management Directives and Planning Guidance

In addition to NPS staff input based on the park's purpose, significance, and fundamental resources and values, and other potential resources/ecological drivers of interest, the NPS Washington (WASO) level programs guided the selection of key natural resources for this condition assessment. This included SODN, I&M NPScape Program for landscape-scale measures, and Air Resources Division for the air quality assessment.

In an effort to improve overall national park management through expanded use of scientific knowledge, the I&M Program was established to collect, organize, and provide natural resource data as well as information derived from data through analysis, synthesis, and modeling (NPS 2011). The primary goals of the I&M Program are to:

- inventory the natural resources under NPS stewardship to determine their nature and status;
- monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other altered environments;
- establish natural resource inventory and monitoring as a standard practice throughout the National Park System that transcends traditional program, activity, and funding boundaries;
- integrate natural resource inventory and monitoring information into NPS planning, management, and decision making; and
- share NPS accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives (NPS 2011).

To facilitate this effort, 270 parks with significant natural resources were organized into 32 regional networks. Tumacácori NHP's part of the SODN, which includes 10 additional parks. Through a rigorous multi-year, interdisciplinary scoping process, SODN selected a number of important physical, chemical, and/or biological elements and processes for long-term monitoring. These ecosystem elements and processes are referred to as 'vital signs', and their respective monitoring programs are intended to provide high-quality, long-term information on the status and trends of those resources. Air quality, climate, groundwater, invasive exotic plants, landbirds, and streams were selected for monitoring at Tumacácori NHP by SODN and park staff (NPS SODN 2018b).

The structural framework for NRCAs is based upon, but not restricted to, the fundamental and other important values identified in a park's Foundation Document or General Management Plan. NRCAs are designed to deliver current science-based information translated into resource condition findings for a subset of a park's natural resources. The NPS State of the Park (SotP) and Resource Stewardship Strategy (RSS) reports rely on credible information found in NRCAs as well as a variety of other sources.

Foundation documents describe a park's purpose and significance and identify fundamental and other important park resources and values. A foundation document was completed for Tumacácori NHP in 2014 (NPS 2014a).

A SotP report is intended for non-technical audiences and summarizes key findings of park conditions and management issues, highlighting recent park accomplishments and activities. NRCA condition findings are used in SotP reports, and each NRCA Chapter 4 assessment includes a SotP condition summary.

A Resource Stewardship Strategy (RSS) uses past and current resource conditions to identify potential management targets or objectives by developing comprehensive strategies using all available reports and data sources including NRCAs. National Parks are encouraged to develop an RSS as part of the park management planning process. Indicators of resource condition, both natural and cultural, are selected by the park. After each indicator is chosen, a target value is determined and the current condition is compared to the desired condition. An RSS has not yet been started for the park.

Status of Supporting Science

Available data and reports varied depending upon the resource topic. The existing data used to assess the condition of each indicator and/or to develop reference conditions are described in each of the Chapter 4 assessments and listed in the Literature Cited section of this report. Important sources of information were the library, central files, and resource management staff files at Tumacácori NHP, the archived collections at the Western Archeological and Conservation Center, the Sonoran Desert Network reference library, and numerous online databases and collections.

In addition to SODN scientists, monitoring of the Santa Cruz River in and around Tumacácori NHP is conducted by the Sonoran Institute (SI) and the Friends of the Santa Cruz River (FOSCR) through their volunteer Riverwatch program, supported by the Arizona Department of Environmental Quality (ADEQ). After conducting a baseline study in the 2008 water year to assess the condition of a 32-km (20-mi) stretch of the river between Rio Rico and Amado (Zugmeyer and McIntyre 2011), the SI initiated their monitoring in 2009 (McIntyre 2010) at randomly selected sites along the upper Santa Cruz River and its major tributaries using methods reviewed and approved by the USEPA and ADEQ (SI 2010). They compare their yearly measurements of 10 indicators (three riparian and seven aquatic) to ADEQ, historical, baseline information, or scientific standards (Zugmeyer and McIntyre 2011) and report their results in the "A Living River" report series.

FOSCR has conducted monthly water quality monitoring since 1992, focusing on the upper Santa Cruz River from its headwaters down to the international border with Mexico and then back up to the border with Pima County from the point where the river re-enters the U.S. The group has compiled the most complete water quality database in existence on the river and freely shares their results (FOSCR 2013).


View along de Anza Trail, Tumacacori National Historical Park. Photo Credit: NPS SODN.

Study Scoping and Design

Tumacácori National Historical Park's (NHP) Natural Resource Condition Assessment (NRCA) was initiated in 2010 as a collaborative effort between the national historical park staff, the National Park Service (NPS) Sonoran Desert Inventory and Monitoring Network (SODN) staff, NPS Intermountain Region, and the Sonoran Institute. A scoping meeting was held at the NHP and focal resources were selected for condition assessment reporting. Various stages of drafts were completed for these selected resources but no final report was produced. In 2017, Utah State University was added as a partner to complete the national historical park's NRCA through a Colorado Plateau Cooperative Ecosystem Studies Unit task agreement, P17AC00921. Original resource topics were retained for condition assessment reporting but new data sets and reference conditions were incorporated, and in some instances, new templates and guidance were added.

Preliminary Scoping

The NRCA scoping meeting for Tumacácori NHP was held at park headquarters in Tumacácori, Arizona, on February 25, 2010, following presentations by SODN staff on the state of the park's natural resources. Attendees included staff members from SODN and the NHP. An overview of the NRCA project was presented by the SODN program manager, followed by a discussion of the management reporting areas for the NHP. Park staff outlined management reporting areas on base maps and identified the primary and/or interpretive themes for each area.

Study Design

Indicator Framework, Focal Study Resources and Indicators

The usefulness, consistency, and interpretation of NRCAs are facilitated by a framework that:

- employs indicators and reference conditions/ values
- analyzes indicator findings to report conditions by ecosystem characteristics
- analyzes indicator findings to report conditions by park areas.

There are several frameworks that meet these criteria, most of which overlap considerably but differ slightly in how they group and split categories. For this NRCA report, the selected natural resources were grouped using the NPS Inventory & Monitoring (I&M) Program's "NPS Ecological Monitoring Framework"

(NPS 2005), which is endorsed by the Washington Office NRCA Program as an appropriate framework for listing resource components, indicators/measures, and resource conditions. Scoping meeting participants identified fundamental and important resources for the NHP that were included in its NRCA. Where applicable, resource topics were incorporated from NHP planning documents, however, topic inclusion was not limited to resources directly identified in those documents. Resources identified during the scoping process were from broad categories, such as animals, plants, geology, soils, hydrology, water quality, water quantity, and invasive species. In total, 10 focal natural resources were selected for resource condition assessment reporting.

Within each resource category, indicators and measures were identified and are listed in Tables 1-3. For each indicator/measure, literature and data sets were identified for condition reporting purposes. Reference conditions were discussed to determine if sufficient context for comparison of the current resource condition existed. Reference conditions provided the point(s) of reference against which current conditions were measured, interpreted, and reported. These were either benchmarks, standards, norms, or thresholds but were not desired conditions or management targets.

Ecological reference conditions (values developed via historic data, modeling site comparisons, best professional judgment, etc.) based on natural resource management priorities and context were primarily used. In some cases, reference conditions were legal or regulatory standards, such as Arizona water quality standards. For resources that lacked sufficient data or context to report on current condition, we provided a descriptive narrative and/or identified important data gaps for that resource within each condition assessment in Chapter 4.

Reporting Areas

Tumacácori NHP is a relatively small park but nine management reporting areas were identified for the NHP. For the purpose of its NRCA, the management reporting areas were defined as specific areas in the NHP that differed in primary management or interpretive themes. It is important to note, however, that these thematic overlays have no official designation for park planning other than as reporting

Table 1. Tumacácori NHP's natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for air and climate.

Resource	Indicators	Measures
Air Quality	Visibility	Haze Index
	Level of Ozone	Human Health
	Level of Ozone	Vegetation Health
	Wet Deposition	Nitrogen
	Wet Deposition	Sulfur
	Wet Deposition	Mercury and Predicted Methylmercury Concentration

Table 2. Tumacácori NHP's natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for water.

Resource	Indicator	Measure
Hydrology	Groundwater	Depth to Groundwater
	Surface Water Quantity	Number of No-Flow Events
	Surface Water Quantity	Number of 50-year or Greater Flow Events
	Surface Water Quantity	Number of Bankfull Events
	Surface Water Quantity	Change in Mean Annual Discharge
	Stream Channel Geomorphology	Sinuosity
	Stream Channel Geomorphology	Cross-sectional Area
	Stream Channel Geomorphology	Dominant Particle Size
	Stream Channel Geomorphology	Particle Size Assessment
Water Quality	Core Water Quality	pH (SU)
	Core Water Quality	Dissolved Oxygen (mg/L)
	Metals and Metalloids	28 Measures
	Nutrients	4 Measures
	Inorganics	Fluoride (mg/L)
	Microbiological Organisms	*E. coli* (cfu/100 ml)
	Benthic Macroinvertebrates	Arizona Index of Biological Integrity
	Benthic Macroinvertebrates	USEPA Multi-metric Index

Table 3. Tumacácori NHP's natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for biological integrity.

Resource	Indicators	Measures
Upland Vegetation and Soils	Erosion Hazard	Bare Ground Cover
	Erosion Hazard	Soil Aggregate Stability
	Erosion Features	Extent of Affected Area by Feature Type
	Site Resilience	Foliar Cover of Dead Perennial Plants
	Site Resilience	Foliar Cover of Dead Perennial Plants
	Fire Hazard	Grass and Forb Cover
	Fire Hazard	Ratio of Annual Plant Cover to Total Plant Cover
	Native Perennial Plant Community Composition and Structure	Cover of Common Species
	Native Perennial Plant Community Composition and Structure	Frequency of Uncommon Species
	Non-native Plants	Extent
	Non-native Plants	Total Cover
	Non-native Plants	Ratio of Non-native Plants to Total Plant Cover
Riparian Vegetation	Loss of Obligate Wetland Plants	Richness and Distribution
	Non-native Plant Dispersal and Invasion	Percent Frequency
	Non-native Plant Dispersal and Invasion	Percent Cover
Birds	Species Occurrence	Richness and Composition
	Species Occurrence	Species of Conservation Concern
	Health	Presence of Avian Pox
	Health	Presence of Heavy Metals
	Health	Reproductive Health
Mammals	Species Occurrence	Species Presence / Absence
	Species Occurrence	Species Nativity
	Species Occurrence	Species of Conservation Concern

Table 3 continued. Tumacácori NHP's natural resource condition assessment framework based on the NPS Inventory & Monitoring Program's Ecological Monitoring Framework for biological integrity.

Resource	Indicators	Measures
Herpetofauna	Species Occurrence	Presence/Absence
	Species Occurrence	Species Nativity
	Species Occurrence	Species of Conservation Concern
Fish	Species Occurrence	Presence/Absence
Bats	Species Occurrence	Presence/Absence
	Species Occurrence	Species of Conservation Concern
	Disease Occurrence	White-nose Syndrome Presence/Absence

areas for the NRCA. These nine areas for the Mission unit of Tumacácori NHP are as follows:

Cultural Resources Demo Site – The cultural resources demo site is primarily managed for interpretation.

Fiesta Grounds – The primary management theme for the fiesta grounds is visitor use for the annual fiesta and the protection of the subsurface cultural resources.

North Agricultural Field – The management focus in this area is preservation of subsurface cultural resources while protecting and maintaining the natural vegetation.

Northwest Terrace – The management theme for this area is protection of archeological sites and the mesquite bosque.

Park Operations – This area is managed for park administration, maintenance, and housing.

Right-of-Way – This area is managed for park administrative purposes.

Riparian System – The management focus in this area is maintaining the natural conditions.

South Agricultural Field – This primary management theme for this field is the protection of the burial ground, which is off limits for development or other uses.

Visitor Use – The primary management themes for this area are the protection of historic structures, interpretation and education, and research.

Both the Calabazas and Guevavi units of Tumacácori NHP are single management reporting areas for which the primary management theme is the preservation and protection of the cultural resources.

General Approach and Methods

Each natural resource condition assessment relied on existing data and literature to evaluate the selected indicators. Additional data analysis was performed as needed. Where possible, data for each measure was compared to a reference condition and a condition, trend, and confidence level status was reported.

The NRCA information manager for Southern Intermountain Region parks led the literature search and data mining effort. The information manager coordinated with park staff to search park libraries and files for NPS reports, other governmental reports, and research documents. In addition to the parks, the information manager searched online data and literature sources and the Western Archeological and Conservation Center. A desktop version of NatureBib was used to manage the literature. During the literature search process, the information manager identified that there was information that was important but outside the scope of the condition assessment project. Therefore, the project team helped analyze the documents for quality and relevancy to the selected indicators. Hard copies of priority documents were scanned as Adobe PDF documents to facilitate sharing among the project team.

Data were found in numerous formats, including spatial, tabular, and prose. Data analysis was specific to each indicator and was described in each assessment in Chapter 4. Tabular data were managed in the most appropriate format (e.g., Microsoft Excel or Access), as determined by the subject-matter expert within the project team. A geographic information system (GIS) was used to manage and display the spatial data, following SODN's standard protocols. The project team utilized ESRI's ArcMap to manage and visualize data. All relevant data were re-projected into the North American Datum 1983 (NAD83) datum and the Universal Transverse Mercator (UTM) zone 12 projection, and Federal Geographic Data Committee (FGDC)-compliant metadata were generated for data collected specifically for the NRCA. The final GIS products, collected specifically for this project, were shared with NHP staff, otherwise weblinks for original data sources were shared.

Following the NPS NRCA guidelines (NPS 2010), each natural resource condition assessment included five sections (note that the literature cited was compiled into one comprehensive list at the end of the report as a separate chapter).

1. The background and importance section of each condition assessment provides information regarding the relevance of the resource to the national monument.
2. The data and methods section describe the existing datasets and methodologies used for evaluating the indicators/measures for current conditions.
3. The reference conditions section describe the good, moderate concern, and significant concern definitions used to evaluate the condition of each measure.
4. The condition and trend section provides a discussion for each indicator/measure based on the reference condition(s). Condition icons are presented in a standard format consistent with State of the Park reporting (NPS 2012b) and served as visual representations of condition/trend/level of confidence for each measure. Table 4 shows the condition/trend/confidence level scorecard used to describe the condition for each assessment, Table 5 provides examples of conditions and associated interpretations.

Circle colors convey condition. Red circles signify that a resource is of significant concern; yellow circles signify that a resource is of moderate concern; and green circles denote that a measure is in good condition. A circle without any color, which is often associated with the low confidence symbol-dashed line, signifies that there is insufficient information to make a statement about condition; therefore, condition is unknown.

Arrows inside the circles signify the trend of the measure. An upward pointing arrow signifies that the measure is improving; double pointing arrows signify that the measure's condition is currently unchanging; a downward pointing arrow indicates that the measure's condition is deteriorating. No arrow denotes an unknown trend.

The level of confidence in the assessment ranges from high to low and is symbolized by the border around the condition circle. Key uncertainties and resource

Table 4. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in good condition.		Condition is Improving.		High
	Resource warrants moderate concern.		Condition is unchanging.		Medium
	Resource warrants significant concern.		Condition is deteriorating.		Low
	An open (uncolored) circle indicates that current condition is unknown or indeterminate; this condition status is typically associated with unknown trend and low confidence.				

Table 5. Example indicator symbols and descriptions of how to interpret them.

Symbol Example	Description of Symbol
	Resource is in good condition; its condition is improving; high confidence in the assessment.
	Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.
	Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.
	Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

threats are treated as a separate section for each resource topic.

5. The sources of expertise list the individuals who were consulted. Assessment author(s) are also listed in this section for each condition assessment.

After the report is published, a disk containing a digital copy of the published report, copies of the literature cited (with exceptions listed in a READ ME document), original GigaPan viewshed images, reviewer comments and writer responses if comments weren't included, and any unique GIS datasets created for the purposes of the NRCA is sent to park staff and the NPS IMRO NRCA Coordinator.


Santa Cruz River along Anza Trail at Tumacácori NHP. Photo Credit: NPS.

Natural Resource Conditions

Chapter 4 delivers current condition reporting for the 10 important natural resources and indicators selected for Tumacácori NHP's NRCA report. The resource topics are presented following the National Park Service's (NPS) Inventory & Monitoring Program's NPS (2005) Ecological Monitoring Framework that is presented in Chapter 3.

Air Quality

Background and Importance

Under the direction of the National Park Service's (NPS) Organic Act, Air Quality Management Policy 4.7.1 (NPS 2006), and the Clean Air Act (CAA) of 1970 (U.S. Federal Register 1970), the NPS has a responsibility to protect air quality and any air quality related values (e.g., scenic, biological, cultural, and recreational resources) that may be impaired from air pollutants.

One of the main purposes of the CAA is "to preserve, protect, and enhance the air quality in national parks" and other areas of special national or regional natural, recreational, scenic, or historic value. The CAA includes special programs to prevent significant air quality deterioration in clean air areas and to protect visibility in national parks and wilderness areas (NPS Air Resources Division [ARD] 2006).

Two categories of air quality areas have been established through the authority of the CAA: Class I and II. The air quality classes are allowed different levels of permissible air pollution, with Class I receiving the greatest protection and strictest regulation. The CAA gives federal land managers responsibilities and opportunities to participate in decisions being made by regulatory agencies that might affect air quality in the federally protected areas they administer (NPS ARD 2005).

Class I areas include parks that are larger than 2,428 ha (6,000 ac) or wilderness areas over 2,023 ha (5,000 ac) that were in existence when the CAA was amended in 1977 (NPS ARD 2010). At 146 ha (360 ac) Tumacácori National Historical Park (NHP) is designated as a Class II airshed (NPS 2014a). However, it is important to note that even though the CAA gives Class I areas the greatest protection against air quality deterioration, NPS management policies do not distinguish between the levels of protection afforded to any unit of the National Park System (NPS 2006).

Air quality is deteriorated by many forms of pollutants that either occur as primary pollutants, emitted directly from sources such as power plants, vehicles, wildfires, and wind-blown dust, or as secondary pollutants, which result from atmospheric chemical reactions. The CAA requires the U.S. Environmental Protection Agency (USEPA) to establish National Ambient Air Quality Standards (NAAQS) (40 CFR part 50) to regulate these air pollutants that are considered harmful to human health and the environment (USEPA 2017b). The two types of NAAQS are primary and secondary, with the primary standards establishing limits to protect human health, and the secondary standards establishing limits to protect

Tumacácori NHP on a partly cloudy day. Photo Credit: NPS.

public welfare from air pollution effects, including decreased visibility, and damage to animals, crops, vegetation, and buildings (USEPA 2017b).

The NPS' ARD (NPS ARD) air quality monitoring program uses USEPA's NAAQS, natural visibility goals, and ecological thresholds as benchmarks to assess current conditions of visibility, ozone, and atmospheric deposition throughout Park Service areas. Visibility affects how well (acuity) and how far (visual range) one can see (NPS ARD 2002), but air pollution can degrade visibility. Both particulate matter (e.g. soot and dust) and certain gases and particles in the atmosphere, such as sulfate and nitrate particles, can create haze and reduce visibility.

Ozone is a gaseous constituent of the atmosphere produced by reactions of nitrogen oxides (NO_x) from vehicles, powerplants, industry, fire, and volatile organic compounds from industry, solvents, and vegetation in the presence of sunlight (Porter and Wondrak-Biel 2011). It is one of the most widespread air pollutants (NPS ARD 2003), and the major constituent in smog. Ozone can be harmful to human health. Exposure to ozone can irritate the respiratory system and increase the susceptibility of the lungs to infections (NPS ARD 2013a).

Ozone is also phytotoxic, causing foliar damage to plants (NPS ARD 2003). Ozone penetrates leaves through stomata (openings) and oxidizes plant tissue, which alters the physiological and biochemical processes (NPS ARD 2013b). Once the ozone is inside the plant's cellular system, the chemical reactions can cause cell injury or even death (NPS ARD 2013b), but more often reduce the plant's resistance to insects and diseases, reduce growth, and reduce reproductive capability (NPS ARD 2015).

Foliar damage requires the interplay of several factors, including the sensitivity of the plant to the ozone, the level of ozone exposure, and the exposure environment (e.g., soil moisture). The highest ozone risk exists when the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions, particularly adequate soil moisture, foster gas exchange and the uptake of ozone by plants (NPS ARD 2013b).

Air pollutants can be deposited to ecosystems through rain and snow (wet deposition) or dust and gases (dry deposition). Nitrogen and sulfur air pollutants are commonly deposited as nitrate, ammonium, and sulfate ions and can have a variety of effects on ecosystem health, including acidification, fertilization or eutrophication, and accumulation of mercury or toxins (NPS ARD 2010, Fowler et al. 2013). Atmospheric deposition can also change soil pH, which in turn, affects microorganisms, understory plants, and trees (NPS ARD 2010). Certain ecosystems are more vulnerable to nitrogen or sulfur deposition than others, including high-elevation ecosystems in the western United States, upland areas in the eastern part of the country, areas on granitic bedrock, coastal and estuarine waters, arid ecosystems, and some grasslands (NPS ARD 2013a). Increases in nitrogen have been found to promote invasions of fast-growing non-native annual grasses (e.g., cheatgrass [*Bromus tectorum*]) and forbs (e.g., Russian thistle [*Salsola tragus*] at the expense of native species (Allen et al. 2009, Schwinning et al. 2005). Increased grasses can increase fire risk (Rao et al. 2010), with profound implications for biodiversity in non-fire adapted ecosystems. Nitrogen may also increase water use in plants like big sagebrush (*Artemisia tridentata*) (Inouye 2006).

According to the USEPA (2017b), in the United States, roughly two thirds of all sulfur dioxide (SO_2) and one quarter of all nitrogen oxides (NO_x) come from electric power generation that relies on burning fossil fuels. Sulfur dioxide and nitrogen oxides are released from power plants and other sources, and ammonia is released by agricultural activities, feedlots, fires, and catalytic converters. In the atmosphere, these transform to sulfate, nitrate, and ammonium, and can be transported long distances across state and national borders, impacting resources (USEPA 2017c), including at Tumacácori NHP.

Mercury and other toxic pollutants (e.g., pesticides, dioxins, PCBs) accumulate in the food chain and can affect both wildlife and human health. Elevated levels of mercury and other airborne toxic pollutants like pesticides in aquatic and terrestrial food webs can act as neurotoxins in biota that accumulate fat and/or muscle-loving contaminants. Sources of atmospheric mercury include by-products of coal-fire combustion, municipal and medical incineration, mining operations, volcanoes, and geothermal vents.

High mercury concentrations in birds, mammals, amphibians, and fish can result in reduced foraging efficiency, survival, and reproductive success (NPS ARD 2013a).

Additional air contaminants of concern include pesticides (e.g., DDT), industrial by-products (PCBs), and emerging chemicals such as flame retardants for fabrics (PBDEs). These pollutants enter the atmosphere from historically contaminated soils, current day industrial practices, and air pollution (Selin 2009).

Data and Methods

The approach we used to assess the condition of air quality within Tumacácori NHP's airshed was developed by the NPS ARD for use in Natural Resource Condition Assessments (NPS ARD 2018). The indicators are visibility (one measure), level of ozone (two measures), and wet deposition (three measures) (Table 6). For conditions, NPS ARD uses all available data from NPS, USEPA, state, and/or tribal monitoring stations to interpolate air quality values, with a specific value assigned to the maximum value within each park. Even though the data were derived from all available monitors, data from the closest stations "outweigh" the rest. Trends were computed from data collected over a 10-year period at on-site or nearby representative monitors. Trends were calculated for sites that have at least six years of annual data and an annual value for the end year of the reporting period.

The haze index is the single measure of the visibility indicator used by NPS-ARD. Visibility is monitored through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program (NPS ARD 2010) and annual average measurements for Group 50 visibility are averaged over a 5-year period at each visibility monitoring site with at least 3-years of complete annual data. Five-year averages are then interpolated across all monitoring locations to estimate 5-year average values for the contiguous U.S. The maximum value within Tumacácori NHP's boundaries is reported as the visibility condition from this national analysis.

Table 6. Summary of indicators and their measures.

Indicators	Measures
Visibility	Haze Index
Level of Ozone	Human Health, Vegetation Health
Wet Deposition	Nitrogen, Sulfur, Mercury, Predicted Methylmercury Concentration

Visibility trends are computed from the Haze Index values on the 20% haziest days and the 20% clearest days, consistent with visibility goals in the CAA and Regional Haze Rule, which include improving visibility on the haziest days and allowing no deterioration on the clearest days. Although this legislation provides special protection for NPS areas designated as Class I, the NPS applies these standard visibility metrics to all units of the NPS. If the Haze Index trend on the 20% clearest days is deteriorating, the overall visibility trend is reported as deteriorating. Otherwise, the Haze Index trend on the 20% haziest days is reported as the overall visibility trend. Visibility trend data were collected at the IMPROVE monitoring station SAGU1, AZ.

The second indicator (ozone) is monitored across the U.S. through air quality monitoring networks operated by the NPS, USEPA, states, and others. Aggregated ozone data were acquired from the USEPA Air Quality System (AQS) database. Note that prior to 2012, monitoring data were also obtained from the USEPA Clean Air Status and Trends Network (CASTNet) database. Ozone trend data were not available because monitoring stations were located farther than 10 km (7 mi), which is the distance at which NPS ARD considers representative for calculating trends (Taylor 2017).

The first measure of ozone is related to human health and is referred to as the annual 4th-highest 8-hour concentration. The primary NAAQS for ground-level ozone was set by the USEPA based on human health effects. The 2008 NAAQS for ozone was a 4th-highest daily maximum 8-hour ozone concentration of 75 parts per billion (ppb). On 1 October 2015, the USEPA strengthened the national ozone standard by setting the new level at 70 ppb (USEPA 2017b). The NPS ARD assesses the status for human health risk from ozone using the 4th-highest daily maximum 8-hour ozone concentration in ppb. Annual 4th-highest daily maximum 8-hour ozone concentrations were averaged over a 5-year period at all monitoring sites. Five-year averages were interpolated for all ozone monitoring locations to estimate 5-year average values for the contiguous U.S. The ozone condition for human health risk at the park was the maximum estimated value within park boundaries derived from this national analysis. There were no on-site or nearby representative monitors to assess human health ozone trends.

The second measure of ozone is related to vegetation health and is referred to as the 3-month maximum 12-hour W126. Exposure indices are biologically relevant measures used to quantify plant response to ozone exposure. These measures are better predictors of vegetation response than the metric used for the human health standard. The annual index (W126) preferentially weighs the higher ozone concentrations most likely to affect plants and sums all of the weighted concentrations during daylight hours (8am-8pm). The highest 3-month period that occurs from March to September was reported in "parts per million-hours" (ppm-hrs), and is used for vegetation health risk from ozone condition assessments. Annual maximum 3-month 12-hour W126 values are averaged over a 5-year period at all monitoring sites with at least three years of complete annual data. Five-year averages were interpolated for all ozone monitoring locations to estimate 5-year average values for the contiguous U.S. The estimated current ozone condition for vegetation health risk at the park was the maximum value within park boundaries derived from this national analysis. There were no on-site or nearby representative monitors to assess vegetation health ozone trends.

The indicator of atmospheric wet deposition was evaluated using three measures, two of which are nitrogen and sulfur. Nitrogen and sulfur were monitored across the United States as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). Wet deposition is used as a surrogate for total deposition (wet plus dry), because wet deposition is the only nationally available monitored source of nitrogen and sulfur deposition data. Values for nitrogen (N) from ammonium and nitrate and sulfur (S) from sulfate wet deposition were expressed as amount of N or S in kilograms deposited over a one-hectare area in one year (kg/ha/yr). For nitrogen and sulfur condition assessments, wet deposition was calculated by multiplying nitrogen (from ammonium and nitrate) or sulfur (from sulfate) concentrations in precipitation by a normalized precipitation. Annual wet deposition is averaged over a 5-year period at monitoring sites with at least three years of annual data. Five-year averages were then interpolated across all monitoring locations to estimate 5-year average values for the contiguous U.S. For individual parks, minimum and maximum values within park boundaries are reported from this national analysis. To maintain the highest level of protection in the park, the maximum value is assigned a condition status. Nitrogen and sulfur condition data were derived by interpolating measured values from multiple monitoring stations located farther than 16 km (10 mi). NPS ARD considers stations located farther than this distance outside the range that is representative for calculating trends (Taylor 2017). As a result, trend data were not available.

The third measure of the wet deposition indicator was evaluated using a mercury risk status assessment matrix. The matrix combines estimated 3-year average (2013-2015) mercury wet deposition (ug/ m^2 yr) and the predicted surface water methylmercury concentrations at NPS Inventory & Monitoring parks. Mercury wet deposition was monitored across the United States by the Mercury Deposition Network (MDN). Annual mercury wet deposition measurements are averaged over a 3-year period at all NADP-MDN monitoring sites with at least three years of annual data. Three-year averages are then interpolated across all monitoring locations using an inverse distance weighting method to estimate 3-year average values for the contiguous U.S. The maximum estimated value within park boundaries derived from this national analysis is used in the mercury risk status assessment matrix.

Conditions of predicted methylmercury concentration in surface water were obtained from a model that predicts surface water methylmercury concentrations for hydrologic units throughout the U.S. based on relevant water quality characteristics (i.e., pH, sulfate, and total organic carbon) and wetland abundance (U.S. Geological Survey [USGS] 2015). The predicted methylmercury concentration at a park is the highest value derived from the hydrologic units that intersect the park. This value was used in the mercury risk status assessment matrix. NPS ARD considers wet deposition monitoring stations located farther than16 kmm (7 mi) outside the range that is representative for calculating trends (Taylor 2017). There were no representative mercury wet deposition monitoring stations for the park.

It is important to consider both mercury deposition inputs and ecosystem susceptibility to mercury methylation when assessing mercury condition, because atmospheric inputs of elemental or inorganic mercury must be methylated before it is biologically available and able to accumulate in food webs (NPS ARD 2013a). Thus, mercury condition cannot be assessed according to mercury wet deposition alone. Other factors like environmental conditions conducive to mercury methylation (e.g., dissolved organic carbon, wetlands, pH) must also be considered (Taylor 2017).

Reference Conditions

The reference conditions against which current air quality parameters are assessed are identified by Taylor (2017) for NRCAs and listed in Table 7.

A haze index estimated at less than 2 dv above estimated natural conditions indicates a "good" condition, estimates ranging from 2-8 dv above natural conditions indicate a "moderate concern" condition, and estimates greater than 8 dv above natural conditions indicate "significant concern." The NPS ARD chose reference condition ranges to reflect the variation in visibility conditions across the monitoring network.

The human health ozone condition thresholds are based on the 2015 ozone standard set by the USEPA (USEPA 2017b) at a level to protect human health: 4th-highest daily maximum 8-hour ozone concentration of 70 ppb. The NPS ARD rates ozone condition as: "good" if the ozone concentration was less than or equal to 54 ppb, which is in line with the updated Air Quality Index breakpoints; "moderate concern" if the ozone concentration was between 55 and 70 ppb; and of "significant concern" if the concentration was greater than or equal to 71 ppb.

The vegetation health W126 condition thresholds are based on information in the USEPA's Policy Assessment for the Review of the Ozone NAAQS (USEPA 2014). Research has found that for a W126 value of:

- ≤ 7 ppm-hrs, tree seedling biomass loss is ≤ 2 % per year in sensitive species; and
- ≥13 ppm-hrs, tree seedling biomass loss is 4-10 % per year in sensitive species.

ARD recommends a W126 of < 7 ppm-hrs to protect most sensitive trees and vegetation; this level is considered good; 7-13 ppm-hrs is considered to be of "moderate" concern; and >13 ppm-hrs is considered to be of "significant concern" (Taylor 2017).

The NPS ARD selected a wet deposition threshold of 1.0 kg/ha/yr as the level below which natural ecosystems are likely protected from harm. This was based on studies linking early stages of aquatic health decline with 1.0 kg/ha/yr wet deposition of nitrogen both in the Rocky Mountains (Baron et al. 2011) and in the Pacific Northwest (Sheibley et al. 2014). Parks with less than 1 kg/ha/yr of atmospheric wet deposition of nitrogen or sulfur compounds are assigned "good" condition, those with 1-3 kg/ha/yr are assigned a "moderate concern" condition, and parks with depositions greater than 3 kg/ha/yr are considered to be of "significant concern."

Ratings for mercury wet deposition and predicted methylmercury concentrations can be evaluated using the mercury condition assessment matrix shown in Table 8 to identify one of three condition categories. Condition adjustments may be made if the presence of park-specific data on mercury in food webs is available and/or data are lacking to determine the wet deposition rating (Taylor 2017).

Table 7. Reference conditions for air quality parameters.

Indicator and Measure	Good	Moderate Concern	Significant Concern
Visibility Haze Index	< 2	2-8	>8
Ozone Human Health (ppb)	≤ 54	55-70	≥ 71
Ozone Vegetation Health (ppm-hrs)	<7	7-13	>13
Nitrogen and Sulfur Wet Deposition (kg/ha/yr)	< 1	1-3	>3
Mercury Wet Deposition (μg/m^2/yr)	< 6	≥ 6 and < 9	≥ 9
Predicted Methylmercury Concentration (ng/L)	< 0.053	≥ 0.053 and < 0.075	≥ 0.075

Source: Taylor (2017)

Note: NPS ARD includes very good and very high standards. In order to conform with NRCA guidance, very low was considered good and very high was considered significant concern condition.

Table 8. Mercury condition assessment matrix.

Predicted Methylmercury Concentration Rating	Mercury Wet Deposition Rating				
	Very Low	Low	Moderate	High	Very High
Very Low	Good	Good	Good	Moderate Concern	Moderate Concern
Low	Good	Good	Moderate Concern	Moderate Concern	Moderate Concern
Moderate	Good	Moderate Concern	Moderate Concern	Moderate Concern	Significant Concern
High	Moderate Concern	Moderate Concern	Moderate Concern	Significant Concern	Significant Concern
Very High	Moderate Concern	Moderate Concern	Significant Concern	Significant Concern	Significant Concern

Source: Taylor (2017).

Condition and Trend

The values used to determine conditions for all air quality indicators and measures are listed in Table 9.

The estimated 5-year (2011-2015) value (6.0 dv) for the historical park's haze index measure of visibility fell within the moderate concern condition rating, which indicates visibility is degraded from the good reference condition of <2 dv above the natural condition (Taylor 2017). For 2006-2015, the trend in visibility at Tumacácori NHP was stable on the 20% clearest days and improved slightly on the 20% haziest days (Figure 5) (IMPROVE Monitor ID: SAGU1, AZ). Confidence in this measure is high because there is nearby visibility monitor. Visibility impairment primarily results from small particles in the atmosphere that include natural particles from dust and wildfires and anthropogenic sources from organic compounds, NO_x and SO_2. The contributions made by different classes of particles to haze on the clearest days and on the haziest days are shown in Figures 6 and 7, respectively, using data collected at the IMPROVE monitoring location, SAGU1, AZ.

The primary visibility-impairing pollutants on the clearest days from 2006-2015 were organic carbon, ammonium sulfates, and coarse mass. On the haziest days ammonium sulfates, organic carbon, and coarse mass were also the primary visibility-impairing pollutants (NPS ARD 2016). Ammonium sulfate originates mainly from coal-fired power plants and smelters, and organic carbon originates primarily from combustion of fossil fuels and vegetation. Sources of coarse mass include road dust, agriculture dust, construction sites, mining operations, and other similar activities.

In 2015, the clearest days occurred during January and February (Figure 8), while the haziest days occurred during August (Figure 9).

Data for the human health measure of ozone were derived from estimated five-year (2011-2015) values

Table 9. Condition and trend results for air quality indicators at Tumacácori NHP.

Data Span	Visibility (dv)	Ozone: Human Health (ppb)	Ozone: Vegetation Health (ppm-hrs)	N (kg/ha/yr)	S (kg/ha/yr)	Wet Mercury (µg/m²/yr)	Predicted Methymercury (ng/L)
Condition	Moderate Concern (6.0) 2011-2015	Moderate Concern (67.1) 2011-2015	Moderate Concern (11.2) 2011-2015	Moderate Concern (1.8) 2011-2015	Good (0.8) 2011-2015	Moderate Concern (6.4) 2013-2015	Significant Concern (0.14) 2013-2015
Trend: 2006-2015	The trend in visibility remained stable on the 20% clearest days and improved on the 20% haziest days (IMPROVE Monitor ID: SAGU1, AZ).						

Source: NPS ARD (2016).

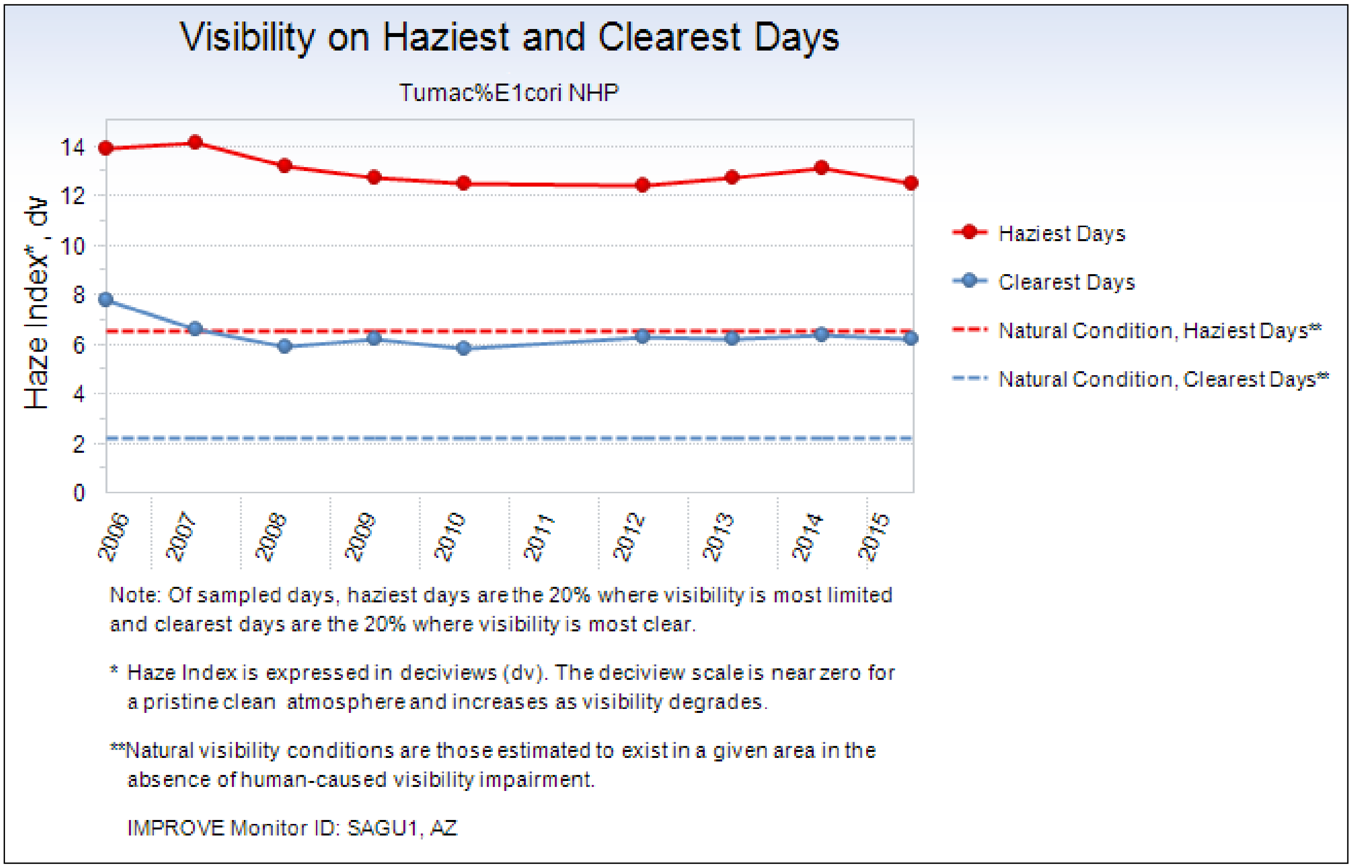


Figure 5. For 2006–2015, the trend in visibility at Tumacácori NHP. Figure Credit: NPS ARD 2016.

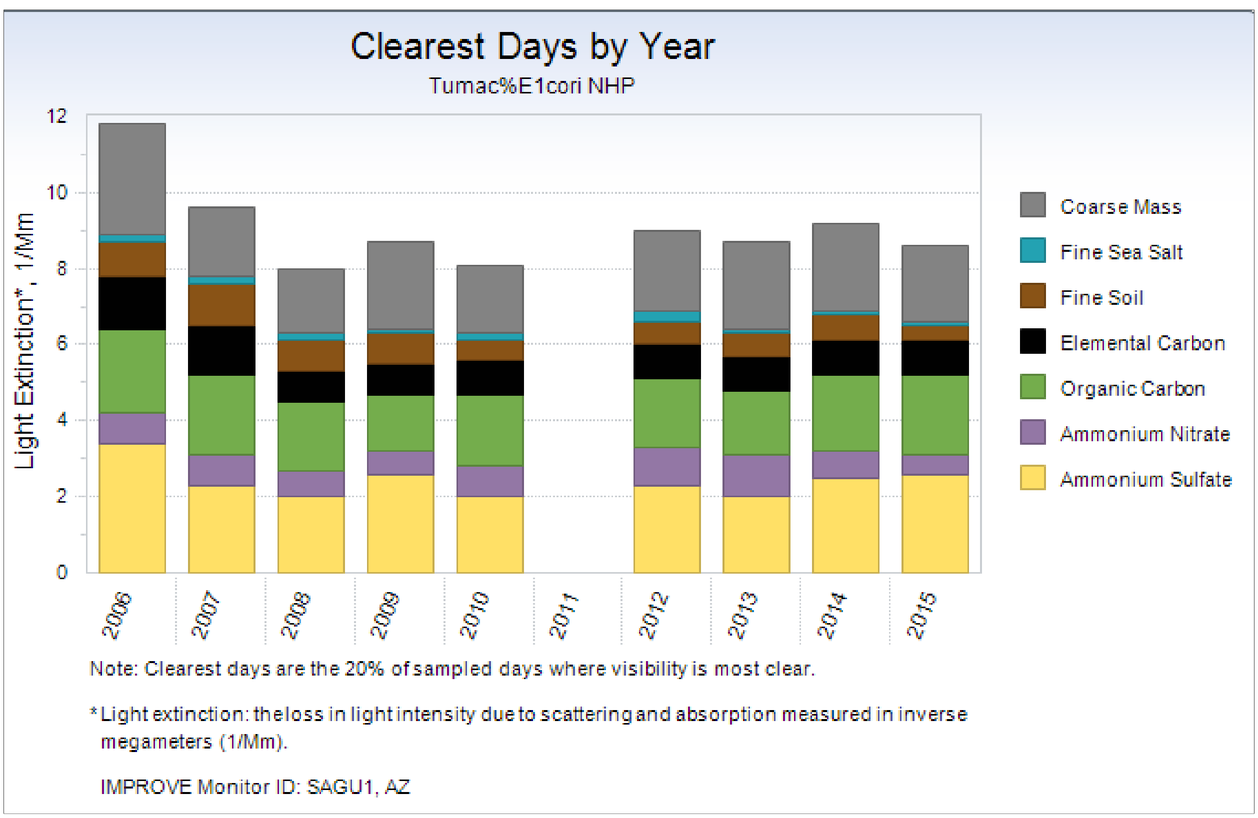


Figure 6. Visibility data collected at SAGU1, AZ IMPROVE station showing the composition of particle sources contributing to haze during the clearest days by year (2006-2015). Figure Credit: NPS ARD 2016.

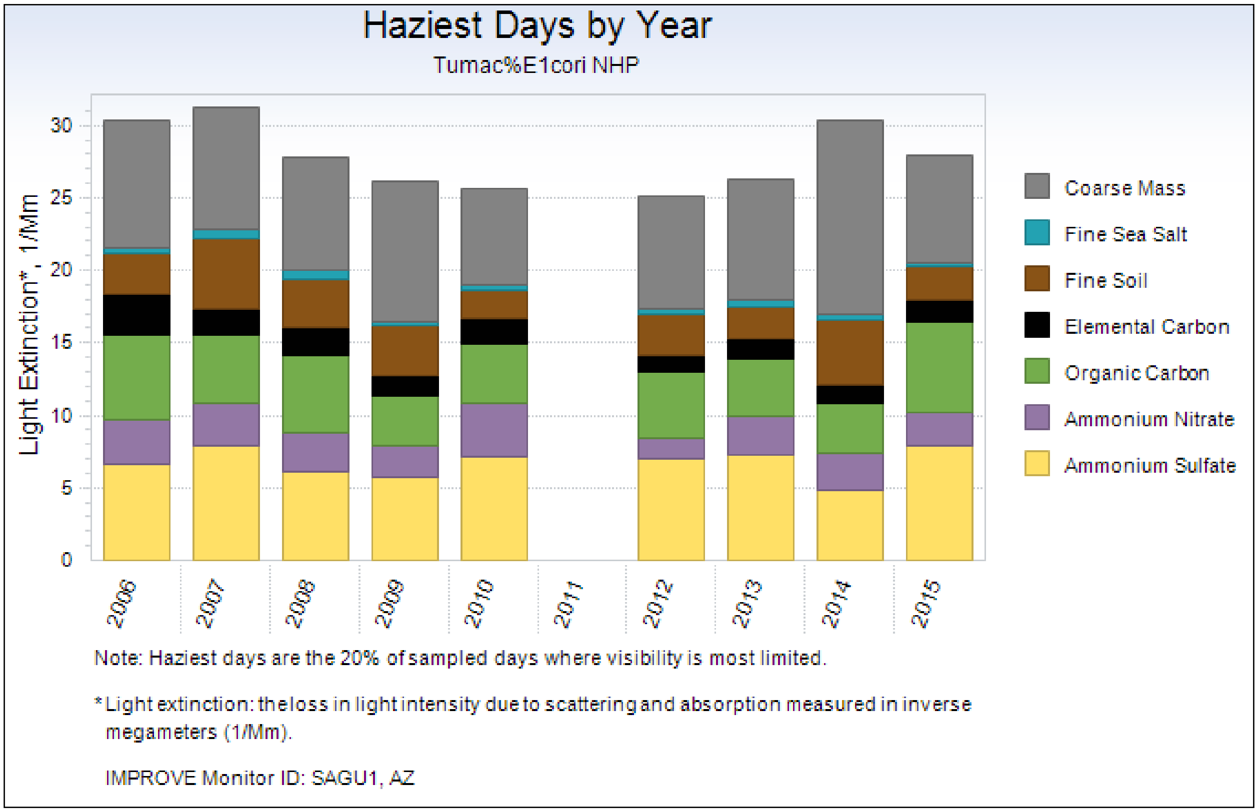


Figure 7. Visibility data collected at SAGU1, AZ IMPROVE station showing the composition of particle sources contributing to haze during the haziest days by year (2006-2015). Figure Credit: NPS ARD 2016.

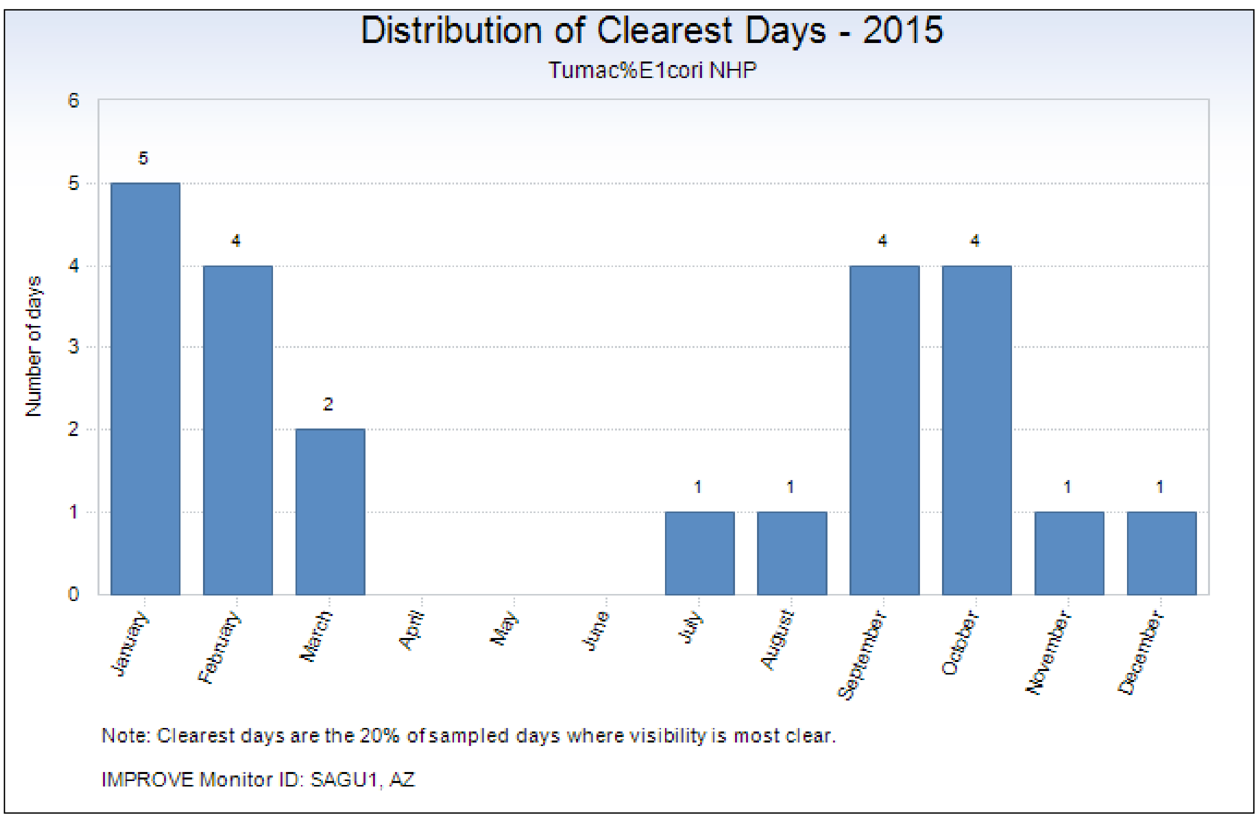


Figure 8. Visibility data collected at SAGU1, AZ IMPROVE station showing the distribution of clearest days by month for 2014. Figure Credit: NPS ARD 2016.

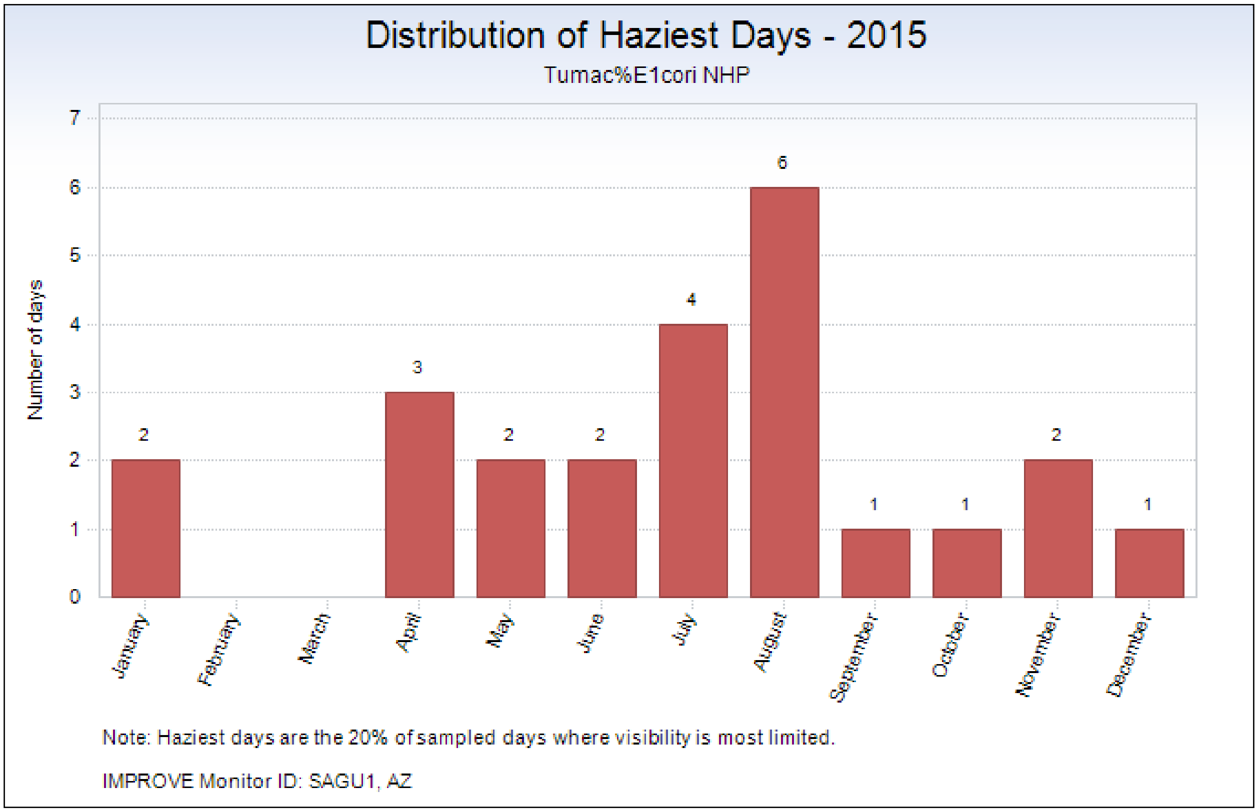


Figure 9. Visibility data collected at SAGU1, AZ IMPROVE station showing the distribution of haziest days by month for 2014. Figure Credit: NPS ARD 2016.

of 67.1 parts per billion for the 4th highest 8-hour concentration, which resulted in a condition rating warranting moderate concern for human health (NPS ARD 2016). Trend could not be determined because there were not sufficient on-site or nearby monitoring data. The level of confidence is medium because estimates were based on interpolated data from more distant ozone monitors.

Ozone data used for the W126 vegetation health measure of the condition assessment were derived from estimated five-year (2011-2015) values of 11.2 parts per million-hours (ppm-hrs). Using these numbers, vegetation health risk from ground-level ozone warrants moderate concern at Tumacácori NHP (NPS ARD 2016). Trend could not be determined because there were not sufficient on-site or nearby monitoring data. Our level of confidence in this measure is medium because estimates were based on interpolated data from more distant ozone monitors.

There are six species of ozone sensitive plants in Tumacácori NHP (Table 10). Of these six species, all but one are considered bioindicators, or species that can reveal ozone stress in ecosystems by producing distinct visible and identifiable injuries to plant leaves (Bell, In Review).

Wet N deposition data used for the condition assessment were derived from estimated five-year average values (2011-2015) of 1.8 kg/ha/yr. This resulted in a condition rating of moderate concern (NPS ARD 2016). No trends could be determined given the lack of nearby monitoring stations. Confidence in the assessment is medium because estimates are based on interpolated data from more distant deposition monitors. For further discussion of N deposition, see the section entitled “Additional Information for Nitrogen and Sulfur” below.

Wet S deposition data used for the condition assessment were derived from estimated five-year average values (2011-2015) of 0.8 kg/ha/yr, which resulted in a good condition rating for Tumacácori NHP (NPS ARD 2016). No trends could be determined given the lack of nearby monitoring stations. Confidence in the assessment is medium because estimates are based on interpolated data from more distant deposition monitors. For further discussion of sulfur, see below.

Table 10. Ozone sensitive plants in Tumacácori NHP.

Scientific Name	Common Name	Bioindicator
Ailanthus altissima	Tree of heaven	Yes
Artemisia ludoviciana	Cudweed sagewort, white sagebrush	Yes
Mentzelia albicaulis	White blazingstar	Yes
Populus fremontii	Freemont's cottonwood	Yes
Salix goodingii	Goodding's willow	No
Sambucus nigra	Black elderberry	Yes

Sullivan (2016) studied the risk from acidification from acid pollutant exposure and ecosystem sensitivity for Sonoran Desert Network (SODN) parks, which includes Tumacácori NHP. Pollutant exposure included the type of deposition (i.e., wet, dry, cloud, fog), the oxidized and reduced forms of the chemical, if applicable, and the total quantity deposited. The ecosystem sensitivity considered the type of terrestrial and aquatic ecosystems present at the parks and their inherent sensitivity to the atmospherically deposited chemicals.

These risk rankings were considered low for estimated acid pollutant exposure and very low for ecosystem sensitivity to acidification (Sullivan 2016). The effects of acidification can include changes in water and soil chemistry that impact ecosystem health. Little has been done regarding the ecological effects of acidification on arid ecosystems in the SODN, but it is unlikely that significant effects have occurred in the network except near metropolitan areas such as Phoenix and Tucson (Sullivan 2016).

Sullivan (2016) also developed risk rankings for nutrient N pollutant exposure and ecosystem sensitivity to nutrient N enrichment. These risk rankings were considered low for nutrient N pollutant exposure and very low for ecosystem sensitivity to nutrient N enrichment. Potential effects of nitrogen deposition include the disruption of soil nutrient cycling and impacts to the biodiversity of some plant communities, including arid and semi-arid communities, grasslands, and wetlands.

Using three datasets, Landscape Fire and Resource Management Planning Tools Project (LANDFIRE), National Wetlands Inventory (NWI) cover data, and National Land Cover Data, nitrogen-sensitive vegetation for the historical park was identified (E&S Environmental Chemistry, Inc. 2009). LANDFIRE and NWI both mapped nitrogen-sensitive communities in Tumacácori NHP (Figure 10). NWI mapped 5 ha (12 ac) of wetlands and LANDFIRE mapped 181 ha (447 ac) of arid and semi-arid communities and 4 ha (10 ac) of grassland and meadow communities. Wetlands occurred only within the Tumacácori Unit.

The Santa Cruz River flowing through Tumacácori NHP is an effluent-driven system (NPS 2014a). An experiment conducted by Marler et al. (2001) designed to simulate the effects of wastewater effluent on riparian plants found that the three species studied responded positively to increased nutrient enrichment (nitrogen and phosphorus) at all concentrations. Non-native saltcedar (*Tamarix ramosissima*) responded with the greatest increase in biomass at high concentrations, while native Goodding willow (*Salix gooddiingii*) and Fremont cottonwood (*Populus fremontii*) exhibited a greater increase in biomass than saltcedar at lower concentrations (Marler et al. 2001). However, atmospheric deposition of N in streams is typically low in the region (Sullivan 2016). Although low levels of nutrient enrichment may favor native species over non-native saltcedar, plant responses at the lowest concentrations were minimal (Marler et al. 2001, Sullivan 2016).

Since the mid-1980s, nitrate and sulfate deposition levels have declined throughout the United States (NADP 2018a). Regulatory programs mandating a reduction in emissions have proven effective for decreasing both sulfate and nitrate ion deposition, primarily through reductions from electric utilities, vehicles, and industrial boilers. In 2007, the NADP/NTN began passively monitoring ammonium ion concentrations and deposition across the U.S. in order to establish baseline conditions and trends over time (NADP 2018b). In 2012 hotspots of ammonium deposition were concentrated in the midwestern states in large part due to the density of agricultural and livestock industries in that region (NADP 2018b). The area surrounding Tumacácori NHP, however, shows relatively low ammonium, sulfate, and nitrate concentrations and deposition levels (NADP 2018a,b). It seems reasonable to expect a continued improvement or stability in sulfate and nitrate deposition levels because of CAA requirements, but since ammonium levels are not currently regulated by the EPA, they may continue to remain high in certain areas (NPS ARD 2010). However, once baseline

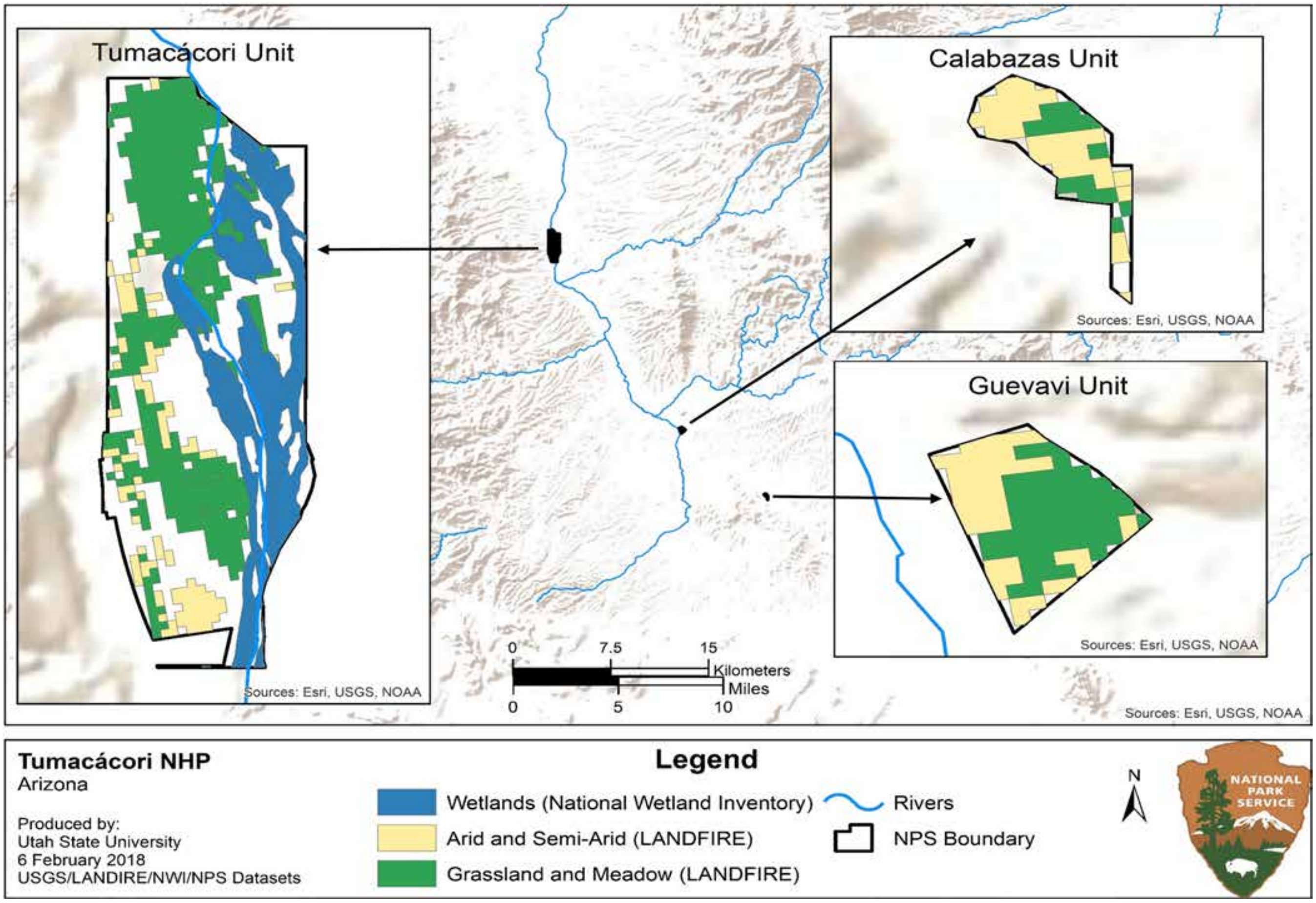


Figure 10. Nitrogen-sensitive plant communities mapped by LANDFIRE and the National Wetlands Inventory at Tumacácori NHP.

conditions for ammonia are established, those data may be used to support regulatory statutes.

Because rainfall in the arid southwest is low, there is relatively little wet S or N deposition (Sullivan 2016). Dry S and N deposition is more common in arid ecosystems but difficult to quantify because many factors influence deposition, including the mix of air pollutants present, surface characteristics of soil and vegetation, and meteorological conditions (Fenn et al. 2003, Weathers et al. 2006). Sparse vegetation may increase the exposure of sols to direct dry deposition of atmospheric pollutants (Sullivan 2016).

The 2013–2015 estimated wet mercury deposition was 6.4 μ/m^2/yr, which warrants moderate at the historical park (NPS ARD 2017a). The predicted methylmercury concentration in park surface waters was very high, estimated at 0.14 ng/L. Wet deposition and predicted methylmercury ratings were combined to determine a significant concern condition status. The degree of confidence in the mercury/toxics deposition condition is low, however, because there were no park-specific studies examining contaminant levels. Trend could not be determined.

Beginning in 2014, up to 50 national parks, including Tumacácori NHP, participated in a citizen science study, Dragonfly Mercury Project (DMP). Students and volunteers collected dragonfly larvae from sampling sites, and the samples were sent to the University of Maine, US Geological Survey, or Dartmouth College laboratories for mercury analyses. According to NPS ARD, "the study will provide baseline data to better understand the spatial distribution of mercury contamination in national parks" (NPS ARD 2017b). Sampling continued in 2017 and the DMP is expected to continue into the future (NPS ARD 2017b).

Overall Condition, Threats, and Data Gaps

For assessing the condition of air quality, we used three air quality indicators with a total of seven measures, which are summarized in Table 11. Based on these indicators and measures, the overall condition of air quality at Tumacácori NHP is of moderate concern. The overall confidence is medium since the values for most measures were collected from more distant monitors and may not necessarily represent conditions with the park, which represents a key uncertainty. A key uncertainty of the air quality assessment is knowing the effect(s) of air pollution, especially of nitrogen deposition, on ecosystems at the park.

Clean air is fundamental to protecting human health, the health of wildlife and plants within parks, and for protecting the aesthetic value of lands managed by the NPS (NPS ARD 2006). The majority of threats to air quality within Tumacácori NHP originate from outside the historical park and include the effects of climate change, forest fires (natural or prescribed), dust created from mineral and rock quarries, and carbon emissions. A proposed mining operation to

Table 11. Summary of air quality indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Visibility	Haze Index		The haze index was within the range considered moderate concern (6.0 dv). There was no trend in the 20% of clearest days, but the trend improved slightly on the 20% of haziest days, for an overall improving trend. Visibility may be impacted by local and regional cities such as Phoenix, Arizona; Las Vegas, Nevada; and Los Angeles, California. Hazy days reduce a visitor's ability to distinguish color, form, and texture. Clear skies are important to visitor enjoyment, especially where the park includes scenic vistas. Dark night skies are also affected by haze.
Level of Ozone	Human Health: Annual 4th-Highest 8-hour Concentration		The five-year (2011-2015) average ozone level as it relates to human health warrants moderate concern. At this level (67.1 ppb), ozone may irritate respiratory systems and increase a person's susceptibility to lung infections, allergens, and other air pollutants.
	Vegetation Health: 3-month maximum 12hr W126		The five-year (2011-2015) ozone level (11.2 ppm-hrs) as it relates to plant health also warrants moderate concern. Some plants are particularly sensitive to high levels of ozone (e.g., lichens, mosses, and liverworts). Plant response to ozone can serve as an early warning sign of air pollution. Shrubs, trees, and herbaceous species may also be affected.
Wet Deposition	N in kg/ha/yr		The five-year (2011-2015) wet deposition of nitrogen (1.8 kg/ha/yr) warrants moderate concern in the park. In excess, nitrogen can cause changes in water and soil chemistry that can have rippling effects throughout the ecosystem. Algal blooms, fish kills, and loss of biodiversity are some of the potential adverse consequences of excess nitrogen in the environment.
	S in kg/ha/yr		Unlike nitrogen, wet deposition of sulfur (0.8 kg/ha/yr) indicated good condition. Excess sulfur deposition can also influence aquatic and terrestrial environments by altering soil and water chemistry with potential rippling effects through the ecosystem. However, this measure indicated wet sulfur deposition was not beyond the range of normal variability.
	Mercury and Predicted Methylmercury Concentration		Mercury/toxics deposition warrants significant concern. Given landscape factors that influence the uptake of mercury in the ecosystem, the status is based on estimated wet mercury deposition and predicted levels of methylmercury in surface waters. The 2013–2015 wet mercury deposition was 6.4 micrograms per square meter per year at the park, and the predicted methylmercury concentration in park surface waters was 0.14 ng/L.
Overall Condition	Summary of All Measures		Air quality data indicate that most measures are degraded from good condition, but trends in visibility have improved. A key data gap is that most measures were interpolated from distant monitors and may not accurately reflect conditions within the park. For this reason, confidence in the overall condition rating is medium. Because data were collected from distant monitors, trends in all but visibility are unknown. While protecting air quality is fundamental to ecosystem health within the NHP, the majority of threats originate from outside the NHP.

the west and east of Tumacácori NHP may impact air quality in the park (NPS 2014a).

Coal-burning power plants are a major source of mercury in remote ecosystems (Landers et al. 2010). Across the SODN region, there are numerous coal-burning power plants (Sullivan 2016). Mercury emissions may threaten ecosystems within the park, including amphibians, invertebrates, and other wildlife that depend on rock pools, springs, and riparian areas. Data from the Mercury Deposition Network for other areas in the southwest suggest that mercury concentrations in rainfall are high. A study examining mercury concentrations in fish from 21 national parks in the western U.S., found that in Capitol Reef NP and Zion NP in Utah, speckled dace (*Rhinichthys osculus*) contained mercury levels that exceeded those associated with biochemical and reproductive effects in fish and reproductive impairment in birds (Eagles-Smith et al. 2014). This was particularly concerning since speckled dace forage on invertebrates, yet exhibited concentrations that were greater than larger, predatory fish species such as lake trout (*Salvelinus namaycush*) (Eagles-Smith et al. 2014).

The western U.S., and the Southwest in particular, has experienced increasing temperatures and decreasing rainfall (Prein et al. 2016). Since 1974 there has been a 25% decrease in precipitation, a trend that is partially counteracted by increasing precipitation intensity (Prein et al. 2016). In Tumacácori NHP, the annual average temperature has significantly increased, but there were no apparent changes in precipitation (Monahan and Fisichelli 2014). One effect of climate change is a potential increase in wildfire activity (Abatzoglou and Williams 2016). Fires contribute a significant amount of trace gases and particles into the atmosphere that affect local and regional visibility and air quality (Kinney 2008). In addition to prescribed burns by the U.S. Forest Service (USFS 2016), natural wildfires have increased across the western U.S., and the potential for the number of wildfires to grow is high as climate in the Southwest becomes warmer and drier (Abatzoglou and Williams 2016). Warmer conditions can also increase the rate at which ozone and secondary particles form (Kinney 2008). Declines in precipitation may also lead to an increase in wind-blown dust (Kinney 2008). Weather patterns influence the dispersal of atmospheric particulates. Because of their small particle size, airborne particulates from fires, motor vehicles, power plants, and wind-blown dust may remain in the atmosphere for days, traveling potentially hundreds of miles before settling out of the atmosphere (Kinney 2008).

Sources of Expertise

The National Park Service's Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units, and provide air quality analysis and expertise related to all air quality topics. Information and text for the assessment was obtained from the NPS ARD website and provided by Jim Cheatham, Park Planning and Technical Assistance, ARD. The assessment was written by Lisa Baril, science writer at Utah State University.

Hydrology

Background and Importance

The Upper Santa Cruz River flows from Nogales, Arizona north to the Santa Cruz-Pima County, Arizona boundary (Brewer and Fabritz-Whitney 2012). Streamflow in this 72-km (45-mi) stretch of river is almost entirely dependent on effluent discharged from the Nogales International Wastewater Treatment Plant, which treats water from both the U.S. and Mexico (Brewer and Fabritz-Whitney 2012). This artificial flow provides an otherwise unavailable quasi-perennial water supply, allowing for the persistence of diverse riparian habitat supporting wildlife and plants. An approximately 2.3-km (1.4-mi) stretch of the Santa Cruz River flows through Tumacácori National Historical Park (NHP) (Gwilliam et al. 2013). Streamflow is supplemented by precipitation, some of which seeps below the Earth's surface to recharge aquifers. Approximately half of the historical park's annual precipitation falls during the monsoon season from July through September (Mau-Crimmins et al. 2005).

Since streams and rivers are generally sensitive to stressors, both locally and at the watershed-level, they are one of the most useful ecosystems to monitor to determine long-term conditions and trends (Mau-Crimmins et al. 2005). However, groundwater is inextricably linked to surface water. Considering both groundwater and surface water together is critical to understanding the hydrologic cycle. Groundwater may reappear at the surface months, years, or even centuries later (Gwilliam et al. 2016). At the right depth, groundwater sustains riparian plants and is the primary source of water for humans across the southwestern U.S. (Stromberg et al. 1996). The potential loss of ground- and surface water in the park due to long-term concerns, such as climate change, groundwater withdrawals outside and inside park boundaries, and changing inputs from the wastewater treatment plant, is of significant concern to park managers (NPS 2014a). This assessment for Tumacácori NHP focuses on groundwater availability, surface water quantity, and the physical characteristics of the stream channel, which influences streamflow, rates of aquifer recharge, and water quality.

Data and Methods

To assess the current condition of hydrology in Tumacácori NHP, we used three indicators with between one and four measures each for a total of nine measures. Indictors and measures were based on the Sonoran Desert Inventory and Monitoring Network (SODN) ground- and surface water monitoring program at Tumacácori NHP (Gwilliam et al. 2014a, 2016, 2017). The three indicators are groundwater, surface water quantity, and stream channel geomorphology.

The Santa Cruz River flowing through Tumacácori NHP. Photo Credit: NPS.

We relied primarily on data collected and provided by the State of Arizona's Department of Water Resources (ADWR 2018) and the U.S. Geological Survey's (USGS) National Water Information System (NWIS) (USGS 2018a). Additional data and background information were available in SODN's three monitoring reports (Gwilliam et al. 2014a, 2016, 2017).

For the first indicator, we used a single measure—depth to groundwater. Depth to groundwater expresses how close the water table is to the Earth's surface (USGS 2016a). The lower the depth to groundwater, the more available water is to riparian plants. Three wells in Tumacácori NHP are included in SODN's monitoring program (Table 12), all of which are located in the historical park's main unit (refer to Figure 3-2 in Gwilliam et al. 2016 for a map of the well locations). The three wells are the Mission well, which provides drinking water to visitors and staff from the most likely the deep water aquifer since well depth is 48 m (156 ft) (Filippone et al. 2014), but the source aquifer was not reported in Gwilliam et al. (2016); the MW-1 shallow well, which accesses the shallow water aquifer; and the MW-1 deep well, which accesses the deep water aquifer (Gwilliam et al. 2016).

Gwilliam et al. (2016) provide the following description for the shallow and deep water aquifers.

> Tumacácori NHP is situated above both shallow and deep aquifers. The deep aquifer lies beneath the shallow aquifer. The shallow, unconfined aquifer, along the Santa Cruz River, is influenced by infiltration from streamflow, groundwater subflow, regional pumping for potable water and irrigation, and transpiration by riparian trees and shrubs. As such, this aquifer exhibits relatively low-magnitude daily cycles. This shallow aquifer has the most direct connection to streamflow, and serves as the primary water source for riparian vegetation.
>
> The deep aquifer at Tumacácori NHP occurs in clayey-sand sediments of the Older Alluvium (Scott et al. 1997), which consists of locally stratified lenses of boulders, gravel, sand, silt, and clays with cemented zones, or caliche. This unit forms the terraces rising above the Santa Cruz River floodplain, and is visible at the roadcut where the northbound access road approaches Interstate 19, near the park. The deep aquifer is buffered from individual weather events and fine-scale variability in flow and evapotranspiration along the Santa Cruz River, and is the source of much of the drinking water in the area, including the park.

Table 12. Wells monitored by SODN.

Well Name	Registration Number	Site ID
Mission Well	55-629110	313406111330201
MW-1 Shallow	55-557439	313345111024802
MW-1 Deep	55-557438	313345111024801

From December 2005 to January 2009, SODN collected data from the shallow and deep aquifer wells, which were installed in 1995 by the University of Arizona (Gwilliam et al. 2016). Beginning in January 2009, the ADWR installed automated water level data collection sensors, and data are now collected continuously at these two wells. MW-1 shallow is screened at a depth of between 9 and 18 m (30 and 60 ft), while MW-1 deep is screened at a depth of between 30 and 35 m (100 and 115 ft). The Mission well has been intermittently monitored since 1960 and several times per year by ADWR since 1998 (Gwilliam et al. 2016). Screen depth for the Mission well was not reported by Gwilliam et al. (2016), but well depth is 48 m (156 ft) (Filippone et al. 2014). Screen depth likely occurs above this depth. Data for these three wells were retrieved through the ADWR website on 14 June 2018 (ADWR 2018). For both the deep and shallow wells, only data collected by ADWR beginning in 2009 were available on the ADWR data portal.

For the surface water quantity indicator, SODN uses four measures that were all based on streamflow. Streamflow data were recorded at the USGS stream gage 09481740 on the Santa Cruz River at Tubac, Arizona. This gage is located 5 km (3 mi) downstream from the Santa Gertrude index reach, which is the sampling site surveyed by SODN in Tumacácori NHP (map available in Gwilliam et al. 2016). The USGS stream gage at Tubac serves as a proxy for stream discharge dynamics at the Santa Gertrudis index reach (Gwilliam et al. 2016). Data for the four measures used to assess the condition of surface water quantity were obtained from the USGS NWIS website on 14 June 2018 (USGS 2018a). Data were reported by water year, which begins October 1 and ends September 30.

The first measure of stream water quantity is the number of no-flow events. We accessed the number of no-flow events through the USGS' water-year (WY) summary tables for the Tubac stream gage (USGS 2018a). Mean daily discharge data were available for WYs 2002 through 2017. A no-flow event was defined as the period during which daily mean flow averaged 0.0 cubic feet per second (cfs), regardless of the number of days in the event. For example, an event could last a single day or more than 30 days. Since the length of the event is also important, we summarized data by the number of events per WY and the dates, or length, of each event. For several years, some mean flow data were estimated, particularly when flows were low (USGS 2018a).

The second measure of surface water quantity is the number of 50-year or greater flood events. The probability of a 50-year flood event is 1 in 50, or a 2% chance of occurrence in any given year (USGS 2018b). According to the USGS StreamStats Data-Collection Station Report for the Tubac stream gage, the flow for a 50-year peak flood would be 14,500 cfs (USGS 2017). A 100-year or greater peak flood would equal or exceed 185,000 cfs (USGS 2017). To determine when or if a 50-year flood event occurred at the stream gage, we downloaded instantaneous peak flow data from the USGS stream gage website (USGS 2018a). Instantaneous peak flow data were available for WYs 1996 to 2015. For WY 2016, we obtained instantaneous peak flow data from Gwilliam et al. (2017). Instantaneous peak flow data were not available for WY 2017.

The third measure of surface water quantity is the number of bankfull events. A bankfull event can be considered a 2-year flood event, which has a 1 in 2 chance of occurring in any given year, or a 50% chance of occurrence (Gwilliam et al. 2013, USGS 2018b). Bankfull events scour channels of fine materials, form bars, and maintain channel structure (Gwilliam et al. 2013). The 2-year flood event flow data provided in the StreamStats Data-Collection Station Report for the Tubac reach was 2,330 cfs (USGS 2017). We determined the years for which the instantaneous peak flow exceeded 2,330 cfs and then examined the summary data for those years to determine the number of bankfull events per WY (USGS 2018a).

The fourth, and final, measure of surface water quantity is change in mean annual discharge. We downloaded mean annual discharge data for WYs 1996 to 2016 from the USGS data portal for the Tubac stream gage and examined trends over time. If there were changes in discharge, we attempted to determine during which hydrologic season changes had occurred. For this analysis, we downloaded mean daily discharge data and calculated totals by season. Hydrologic seasons were defined by dates as follows: 11 October - 7 December; 8 December - 30 April; 1 May - 4 July; and 5 July - 10 October as described in Tumacácori NHP's baseline water quality report (NPS 2003).

Stream channel geomorphology is an important indicator of watershed condition, integrating both biological and geomorphological processes (e.g., soil erosion, nutrient cycling, discharge characteristics, disturbance events, and surface and groundwater quality and quantity) (Gwilliam et al. 2013). Geomorphology data were collected by SODN staff at the Santa Gertrudis index reach located in the historical park. SODN's stream sampling protocol has not been published as of the writing of this assessment so we could not provide details on data collection methods. Instead, we provide a brief description of each measure and its significance.

Sinuosity is a measure of the length of the channel thalweg (lowest point in the stream channel) to the length of the stream valley as measured between the same two points (Rosgen 1996). Sinuosity determines how well a stream dissipates energy. Water in a stream with low sinuosity flows at a higher rate than a stream with high sinuosity (Rosgen 1996). High water flows accelerate erosion, which further alters sinuosity. Sinuosity depends on the landscape setting and is different for each stream (Rosgen 1996).

Cross-sectional area refers to the channel capacity, or size of the river channel cross-section to bankfull stage (Rosgen 1996). This measure varies with position in the stream and discharge. Changes in discharge will alter the shape of the channel. Higher discharge rates will result in a deeper and wider stream, while lower discharge rates will result in a narrower, shallower channel (Rosgen 1996).

The dominant particle size can inform stream flow characteristics with larger particles present in higher-gradient streams than streams with smaller particles (Rosgen 1996). Bedrock, boulder, cobble, gravel, sand, and silt/clay are sediment/particle composition types. The relative composition of these particle sizes provides clues to stream flow velocity and gradient (Rosgen 1996). We summarized data provided in Gwilliam et al. (2014a, 2017).

The purpose of the particle size assessment is to determine changes in particle size, particularly from coarse to fine particles (Gwilliam et al. 2013). Fine particles are an indicator of erosion, and fine particles can have detrimental effects on benthic macroinvertebrates (Gwilliam et al. 2013). As with dominant particle size, we summarized data provided in Gwilliam et al. (2014a, 2017).

Reference Conditions

Reference conditions are described for resources in good or moderate/significant concern conditions (Table 13). Except for depth to groundwater and change in mean annual trend in discharge, reference conditions for all measures were based on Management Assessment Points (MAPS) developed by SODN for Montezuma Castle and Tuzigoot national monuments (Gwilliam et al. 2013). MAPS "represent preselected points along a continuum of resource-indicator values where scientists and managers have together agreed that they want to stop and assess the status or trend of a resource relative to program goals, natural variation, or potential concerns" (Bennetts et al. 2007). MAPS do not define management goals or thresholds. Rather, MAPS "serve as a potential early warning system," where managers may consider possible actions and options (Bennetts et al. 2007).

For depth to groundwater, research has shown that a maximum depth of 3.2 m (10.5 ft) and 5.1 m (16.7 m) is required to sustain mature willow (*Salix* spp.) and cottonwood (*Populus* spp.) trees, respectively (Stromberg et al. 1996). For juvenile willows and cottonwoods, a maximum depth of 2.0 m (6.6 ft) is required (Stromberg et al. 1996). To ensure the persistence of woody riparian plants at all life stages, we conservatively set the good reference condition at a depth of 2.0 m (6.6 ft) or less. For mean annual trend in discharge, a stable or improving discharge would indicate good condition, while a decline in discharge would indicate moderate/significant concern.

Condition and Trend

At the Mission well, most depth to groundwater measurements ranged from 3.2 m (10.5 ft) to 5.1 m (16.7 ft), which represents adequate water levels for mature cottonwood trees but not for mature willows or juveniles of either species (Figure 11). It's important to note, that data were intermittently collected at the Mission well from 1960 and 1998, and then only several times per year thereafter. Data for the shallow aquifer well indicate that the water level is adequate for maintaining mature riparian trees of both species but not juveniles (Figure 12). The average depth to groundwater for the shallow well was 3.1 m (10.0 ft). Filippone et al. (2018) state that "the shallow aquifer has the most direct connection to streamflow, and serves as the primary water source for riparian vegetation." The shallow aquifer also responds more readily to precipitation than the deep aquifer and is the primary source of groundwater withdrawals in the

Table 13. Reference conditions used to assess hydrology.

Indicators	Measures	Good	Moderate/Significant Concern
Groundwater	Depth to Groundwater	≤2.0 m	>2.0 m
Surface Water Quantity	Number of No-Flow Events	0	>0
	Number of 50-year or Greater Flow Events	Max flow <50-year return interval discharge.	Max flow >50-year return interval discharge.
	Number of Bankfull Events	≤2	>2
	Change in Mean Annual Discharge	No changes in discharge have occurred during the period of record or discharge has improved.	Discharge has declined, particularly in recent years.
Stream Channel Geomorphology	Sinuosity	≤10% change	>10% change
	Cross-sectional Area	≤10% change in any one cross-section, or of the total cross-sectional area.	>10% change in any one cross-section, or of the total cross-section area.
	Dominant Particle Size	No change in one type to another.	Change from one type to another.
	Particle Size Assessment	Fine particle size increase of no more than 10%.	Fine particle size increase >10%.

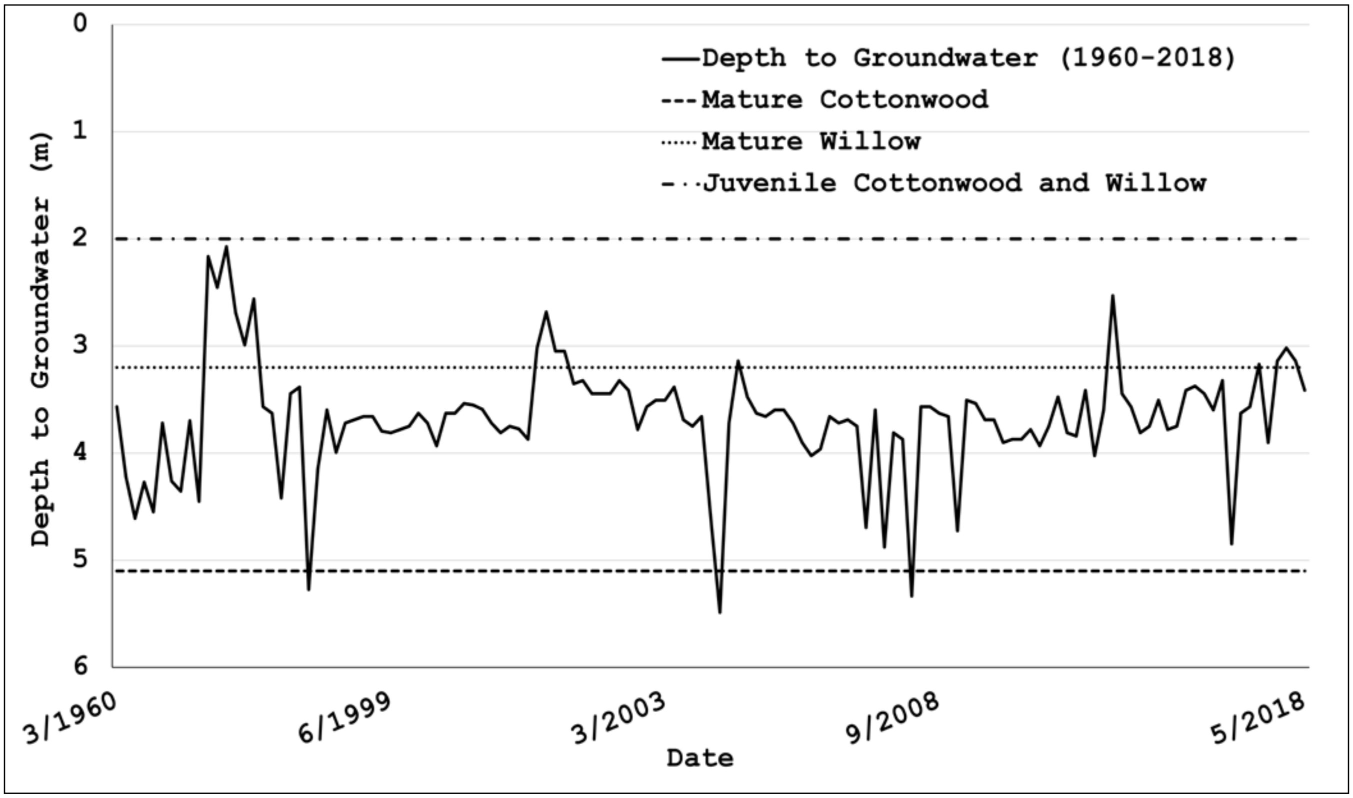


Figure 11. **Depth to groundwater at the Mission well in Tumacácori NHP (1960-2018) and maximum depth for sustaining woody riparian vegetation.**

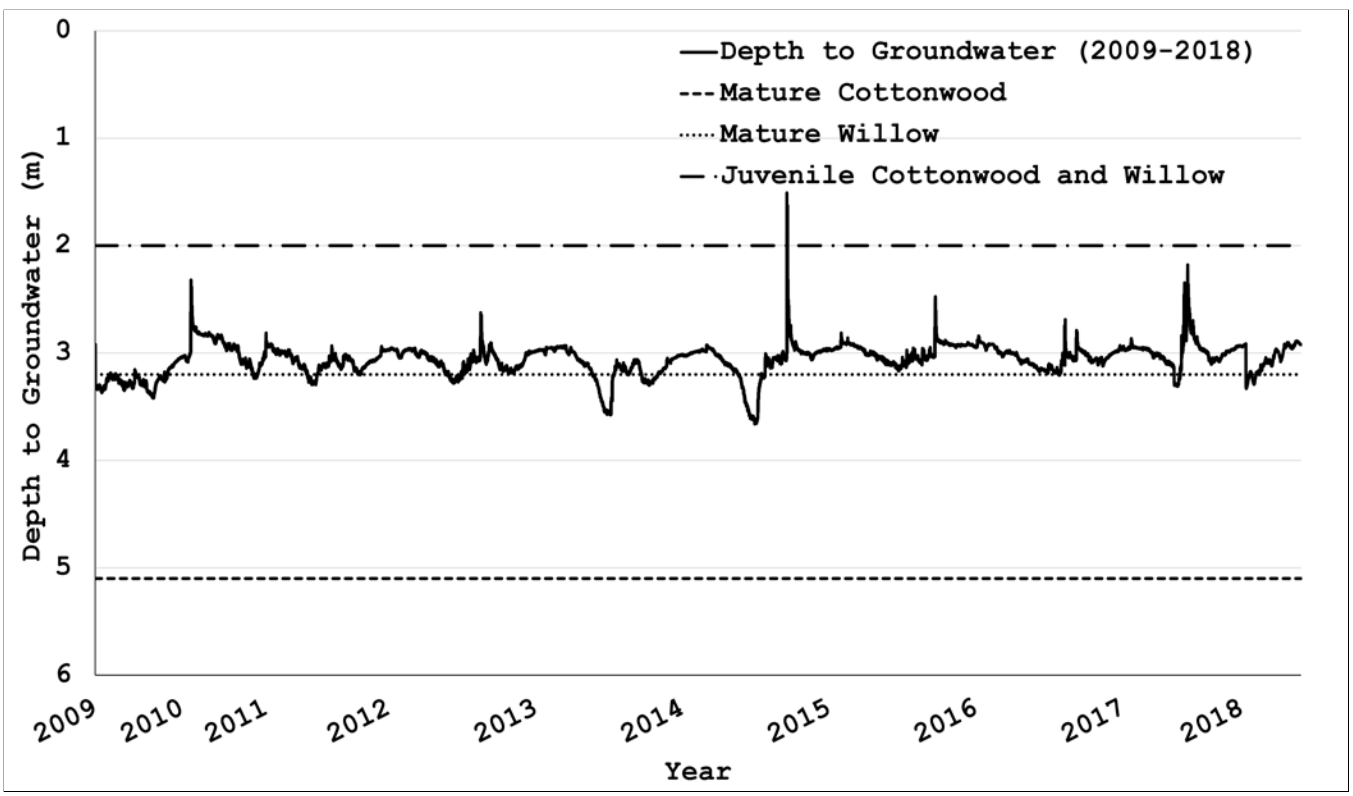


Figure 12. **Depth to groundwater at the shallow aquifer well in Tumacácori NHP (2009-2018) and maximum depth for sustaining woody riparian vegetation.**

region (ADWR 2012, Gwilliam et al. 2016). As a result, the deep aquifer well exhibited a narrower range of variability than the shallow aquifer well (Figure 13).

Although seasonal fluctuations can be observed in the deep well, they are less obvious than in the shallow aquifer well. However, there may be a defect in the deep well casing, which may partially account for the unexpected seasonal fluctuations (Gwilliam et al. 2016). The defect in the casing may draw deep aquifer water into the shallow aquifer, but it is unclear how these two wells are linked (Gwilliam et al. 2016, Filippone et al. 2018). Regardless, these data indicate that only mature cottonwoods may be retained along the riparian area, while recruitment of woody riparian vegetation may not be possible. Based on these data, the overall condition for depth to groundwater is of moderate/significant concern. A simple linear regression analysis shows a significant trend toward improving conditions in both the shallow (R^2 = 0.05, p = <0.05, t = -26.14) and deep (R^2 = 0.50, p < 0.05, t = -116.20) wells, but because of the possible compromise in the deep well casing, we did not assign a trend. Furthermore, the R^2 value for the shallow well (0.05) was low, indicating large variability in the data. Confidence is medium because of issues with the well casing.

According to the USGS water-year summaries (October 1995 to September 2017), seven of 16 years exhibited at least one no-flow event lasting from one to 53 days (Table 14). WYs 2013 and 2014 exhibited the most and longest (WY 2014) no-flow events since 2002. From 2002 to 2012, most of the no-flow events occurred during the summer season, which is typically the driest time of year. However, post-2012 no-flow events began occurring during the monsoon season, which is typically the wettest time of the year. Monsoon rains are critically important for recharging streams and aquifers. It should be noted that for WYs 2011, 2012, 2013, and 2014, some or all of the data for the no-flow events were estimated (USGS 2018a). In Gwilliam (2013), the author states that the Santa Cruz River in the historical park was dry from mid-April through August. However, USGS data indicate that the river at the Tubac gage downstream of the park did not go dry until June (Table 14). This apparent discrepancy could be due to faulty instrumentation or it could be that discharges above 0.0 cfs but below a certain threshold are effectively ecologically insignificant. This suggests that the data provided in Table 14 are conservative. Despite the conservative nature of the data, the number of years with no-flow events, especially most recently from 2015-2017, and the number of no-flow events by year warrants

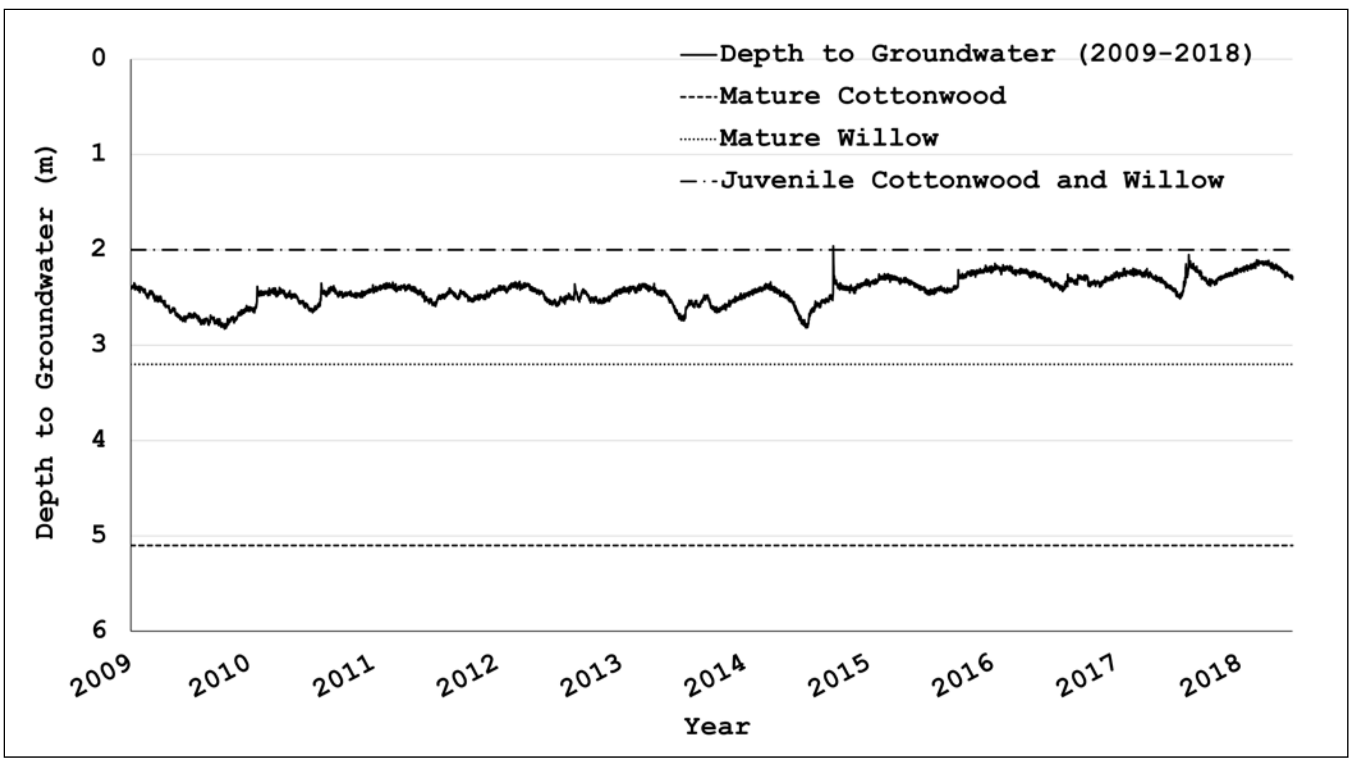


Figure 13. Depth to groundwater at the deep aquifer well in Tumacácori NHP (2009-2018) and maximum depth for sustaining woody riparian vegetation.

Table 14. Summary of no-flow events.

Water Year	# Events	Max Length of Events (days)	Event Dates
2002	1	33	19 May - 20 June
2003	2	38	4 June - 11 July, 14-19 July
2010	3	37	11 June - 17 July, 13-19 July, 25 July
2011*	1	29	9 June - 7 July
2012*	2	6	15-16 June, 18-23 June
2013*	7	15	6-8 November, 1 June - 6 July, 1 August; 9-14 August, 16-19 August; 21 August, 16-30 September
2014*	4	53	1 October - 22 November, 19 May - 6 July, 18-19 July, 21-24 July

* Indicates some or all of data were estimated.

moderate/significant concern. The high variability in the data precluded trend analysis. Confidence in the condition rating is high since even conservative estimates of no-flow events warrants moderate/significant concern.

There were no 50-year or greater flow events recorded at the Tubac stream gage during 1996 to 2016 (Figure 14). The largest peak flood events on record occurred during 2001 (10,600 cfs) and 2007 (10,300 cfs). Therefore, the condition is good. Confidence is high. Trend is unchanging.

The number of bankfull events ranged from none to at least two per WY from 1996 to 2016 (Figure 14, Table 15). All but one bankfull event occurred during the monsoon season. However, for five of the nine WYs in which bankfull events occurred, we could not determine whether there was more than one bankfull event given the way data were organized on the USGS data portal (i.e., only some years were summarized by instantaneous flows greater than 2,330 cfs). Therefore, we could not determine if the reference for good condition was exceeded for these five years. However, for the remaining 15 years, the reference condition of no more than 2 bankfull events was not exceeded. Therefore, the condition is good but confidence is low. Trend could not be determined.

There was no trend in mean annual discharge from WY 1996 to WY 2017 ($R^2 = 0.08$, $p = 0.23$, $t = -1.25$); however, from WY 2005 to WY 2012, there was an

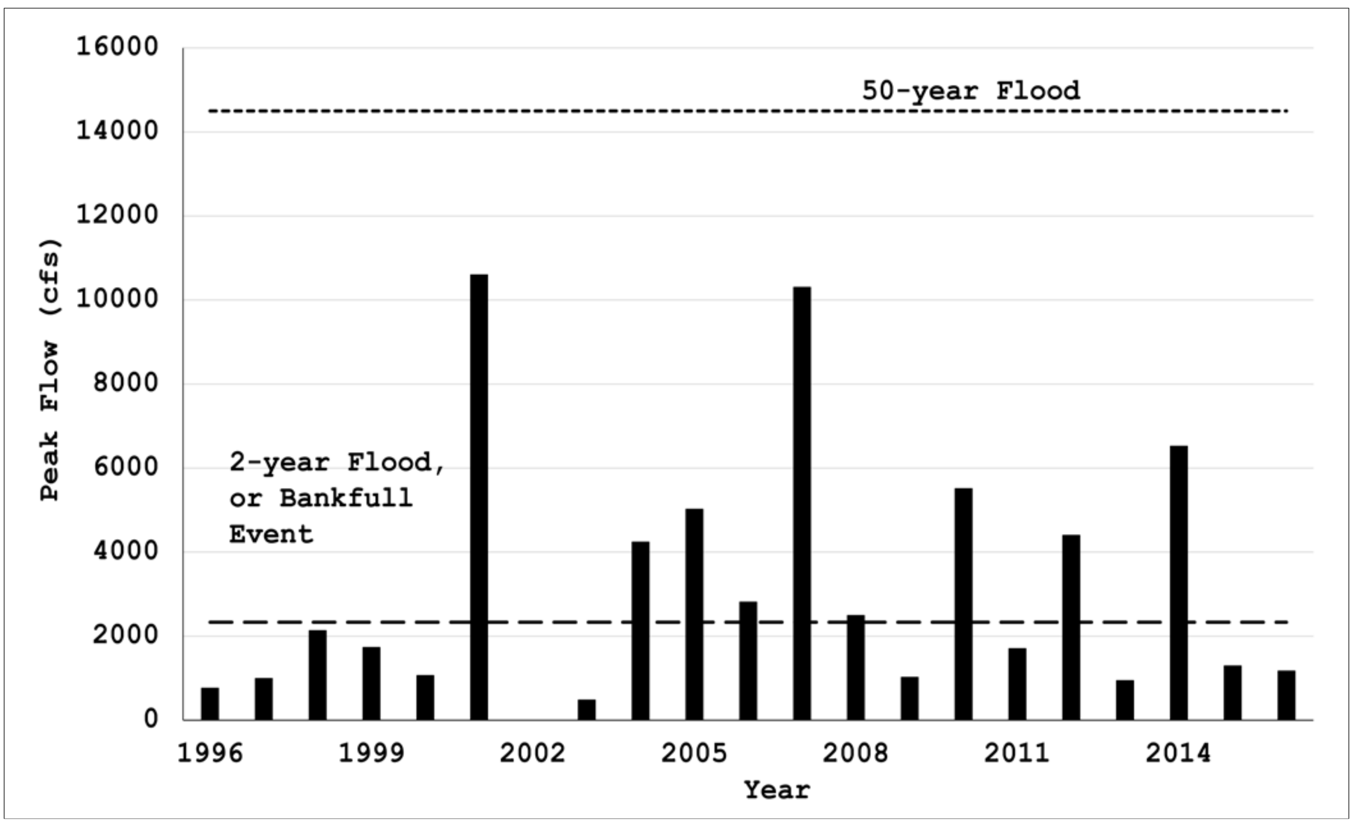


Figure 14. Instantaneous peak annual flow at the USGS Tubac stream gage (1996-2016).

Table 15. Summary of bankfull events.

Water Year	Number of Events	Dates
1996	0	n/a
1997	0	n/a
1998	0	n/a
1999	0	n/a
2000	0	n/a
2001	1*	23 October
2002	0	n/a
2003	0	n/a
2004	1*	8 July
2005	1*	31 July
2006	2	29 & 31 July
2007	1	2 August
2008	1	12 July
2009	0	n/a
2010	1	31 July
2011	0	n/a
2012	1*	17 August
2013	0	n/a
2014	1*	18 September
2015	0	n/a
2016	0	n/a

* Indicates minimum number of bankfull events.

obvious decline in mean annual discharge (Figure 15). Discharge then increased in 2014, declined for two years, and then peaked in 2017 (see inset in Figure 15). This increase in streamflow is attributed to higher than average rainfall since 2014, which has partially mitigated the long-term drought that began in 2000 (Gwilliam et al. 2017). Seasonal discharge was most variable during the monsoon season and least variable during summer (Figure 16). Some of the variability during the monsoon season can be attributed to the apparently increasing number of no-flow events, but this season is naturally historically variable (Shamir et al. 2015). Simple linear regression analyses for each season over the total 22-year period indicate a significant declining trend in discharge for spring ($R^2 = 0.22$, $t = -2.43$, $p = 0.02$), summer ($R^2 = 0.21$, $t = -2.33$, $p = 0.03$), and winter ($R^2 = 0.38$, $^t = -3.51$, $p = 0.002$). The decline in mean annual discharge in recent years and long-term declines in total discharge for three of the four seasons warrants moderate/significant concern for the historical park. Trend is deteriorating. Confidence in the condition rating is high.

To date, SODN staff have evaluated measures of stream channel geomorphology at the Santa Gertrudis index reach once (NPS, E. Gwilliam, ecologist, e-mail

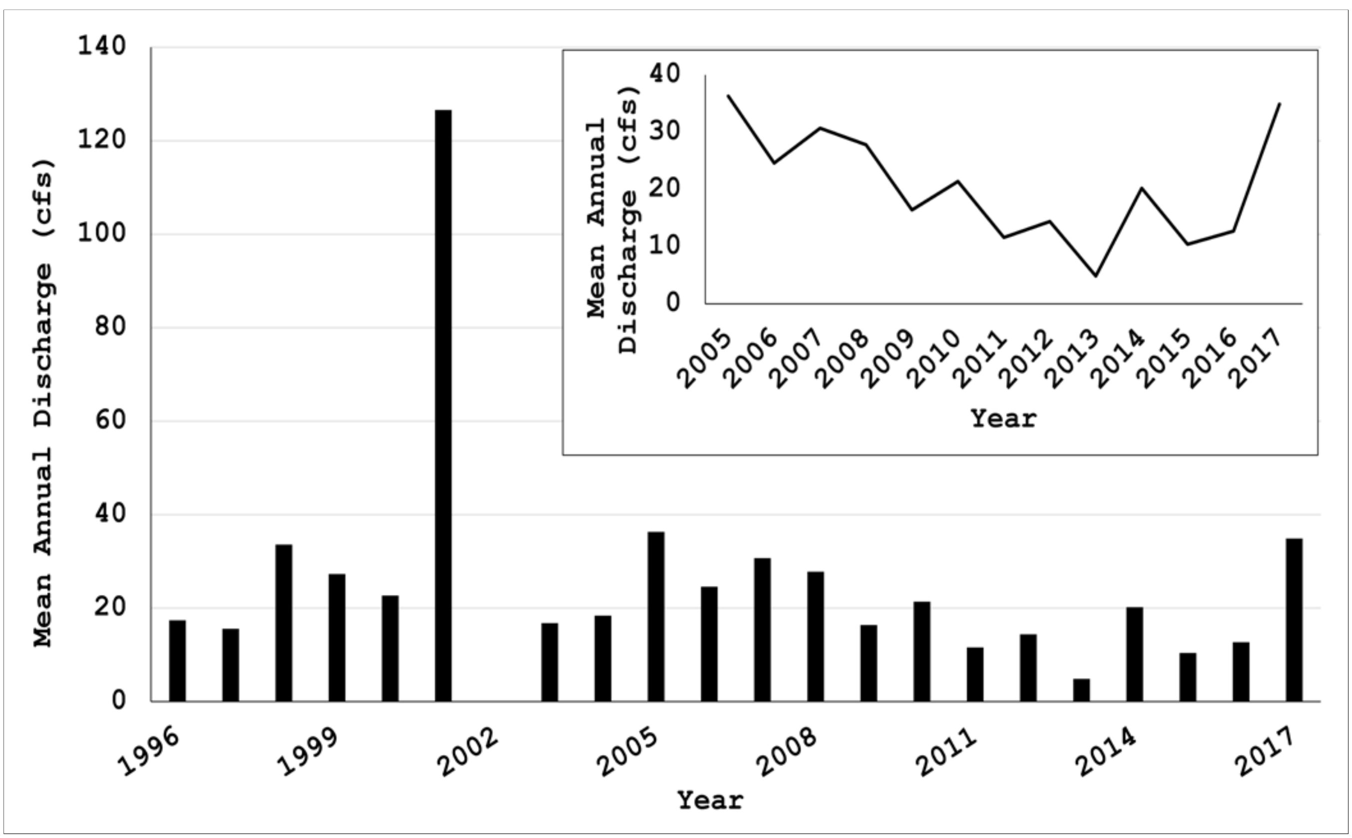


Figure 15. Mean annual discharge at the Tubac stream gage (1996-2016).

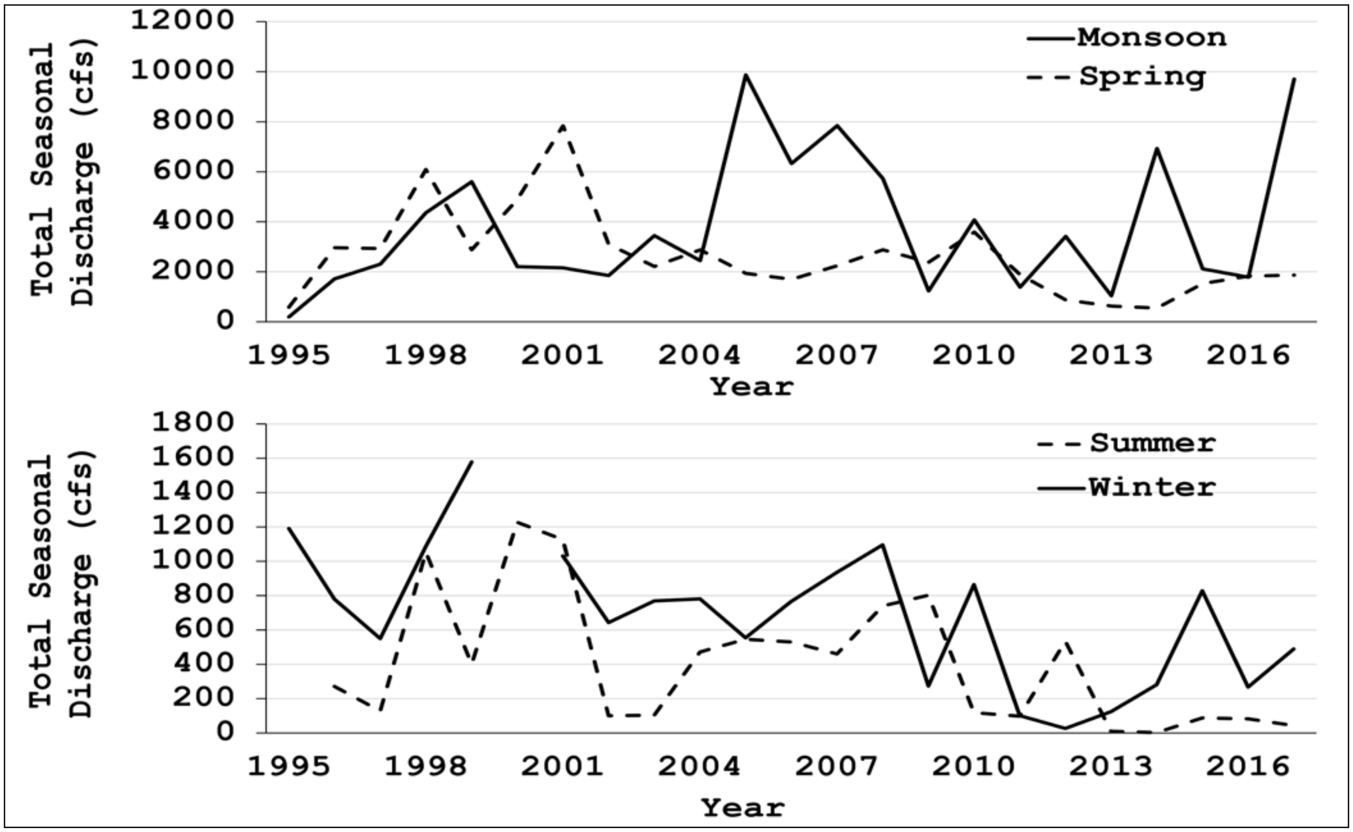


Figure 16. Total annual discharge at the Tubac stream gage (1996-2016).

message, 6 February 2018). Data for two of the four measures (sinuosity and cross-sectional area) were not available for this report. Since reference conditions for these two measures are based on change over time, the conditions and trends for sinuosity and cross-sectional area are unknown. Confidence is low because of the unknown condition rating. Trend is also unknown.

For the dominant particle size measure, SODN reported that in WY 2011 the index reach was dominated by sand followed by gravel (Gwilliam et al. 2014a). Cobble was only observed in one location along the stream reach, and silt tended to occur along the edges of wetted channels. Gwilliam et al. (2014a) reported that the Bank Erosion Hazard Index for the Santa Cruz River was low to moderate. Although the channel was dominated by sand, which is prone to erosion, riparian plant cover over the wetted channel was high (47.8%) (Gwilliam et al. 2014a). Riparian plants reduce erosion by stabilizing stream banks. In addition, streambanks occurred at low angles, which further reduces erosion hazard (Gwilliam et al. 2014a).

In WY 2016, the index reach was also dominated by sand followed by gravel. The dominance of these particle types is the result of large, stochastic floods that occur during the monsoon season (Gwilliam et al. 2017). The proportion of each particle type was reported for WY 2016 with a comparison to the average for WYs 2011-2015 (refer to Figure 3-7 in Gwilliam et al. 2017). The figure shows that the dominant particles were sand in WY 2016 and gravel for WYs 2011-2015. However, comparing a 5-year average to a single year is not as informative as comparing individual years. Since the substrate was dominated by sand in both WYs 2011 and 2016, the condition is good, but confidence is medium given the absence of published annual data for WYs 2012 through 2015. Trend is unknown but appears unchanging.

For the particle size assessment measure, SODN reported that in WY 2011 particle size in riffles had a median size of 11 mm (0.4 in) (Gwilliam et al. 2014a). Riffle habitat is normally characterized by boulders and cobbles with a median size of 64 mm (2.5 in) (Gwilliam et al. 2014a). As described above, the whole index reach in WY 2011 was dominated by sand, which has a diameter of <2.8 mm (0.1 in). In WY 2016, the dominant substrate was also sand along the entire reach, but in riffle habitat, the dominant particle size had a median of 16 mm (0.6 in) (Gwilliam et al. 2017). This is similar to WY 2011. However, data from WYs 2012-2015 were not available. Although the particle size appears to have not transitioned to a smaller particle size (i.e., clay/silt), which indicates good condition, confidence is medium because only two years of data were reported. Trend appears unchanging, but because of the low confidence, we did not assign trend.

Overall Condition, Threats, and Data Gaps

Based on the measures used in this assessment, the condition of hydrologic resources at Tumacácori NHP warrants moderate/significant concern, primarily as a result of declines in surface water in the Santa Cruz River, the prevalence of no-flow events, and a persistently low groundwater table (Table 16). Measures with high confidence were given more weight in the overall condition rating than measures with medium or low confidence, and measures without a condition rating were not used to assess overall condition. Confidence in the overall condition rating is high because of the length of the data used to assess measures of groundwater and surface water quantity. Most measures were not assigned a trend and only one measure was assigned a deteriorating trend (change in mean annual discharge) so overall trend could not be determined. A key uncertainty pertains to the number of bankfull events for those years during which only one event could be identified due to the structure of the USGS data.

Declining streamflow reduces recharge of the shallow water aquifer. Changes in stream flow and groundwater will reduce the available habitat for obligate and facultative wetland plants—such as willows and cottonwoods—and increase the susceptibility of invasion by non-native species and promote encroachment by upland species (Stromberg et al. 1996). In Tumacácori NHP, this could mean an increase of the mesquite bosque habitat. Currently however, the availability of groundwater, at least for mature cottonwoods and willows, appears good. Although current groundwater levels are not adequate for juveniles of both species, the 2007-2008 vegetation mapping project found extensive cottonwood and willow forest along the Santa Cruz River in the park (Drake et al. 2009). Riparian vegetation is addressed in a separate assessment.

While woody riparian plants are persisting in Tumacácori NHP, prolonged drought stress will eventually cause mortality. Even deep-rooted, well-established cottonwood trees are susceptible to annual changes in groundwater and streamflow. In 2013 for example, cottonwoods along the Santa Cruz River in Tumacácori NHP dropped their leaves in response an extended absence of flowing water (Gwilliam 2013). Despite these results, there has been a general increase in riparian obligate plants along the riparian corridor since the 1930s as a result of agricultural abandonment, but some of these trees are decadent (Buckley 2012).

Declining streamflow will also adversely affect aquatic wildlife. The endangered Gila topminnow (*Poeciliopsis occidentalis*) only recently returned to the Santa Cruz River in 2015 and Tumacácori NHP in 2016 (Gwilliam et al. 2017, Zugmeyer 2016). The absence of flows will eliminate habitat for this species and their food source, benthic macroinvertebrates. The absence of flowing water or reduced flows will also alter the geomorphic characteristics of the stream channel. However for the time being, the recolonization of native fish to the stream indicate that water quality is generally good. We reported macroinvertebrate data as a measure of water quality in the water quality assessment in this report. Although macroinvertebrate data warranted significant concern from 2012 to 2017, Filippone et al. (2018) write that despite values that indicate concern, the diverse and stable abundance of mayflies and caddisflies and low abundance of poor water quality indicators such as midge larvae suggest that water quality and macroinvertebrate habitat in the stream reach was generally good in WY 2017, especially considering that this reach of the Santa Cruz River is effluent-dependent.

The shallow water aquifer is the primary source of water for the surrounding communities (ADWR 2012). The municipal, industrial, and agricultural demands of water in the Santa Cruz watershed have increased over time, with agricultural demands accounting for anywhere between 52% and 72% of the total water demand in a given year (ADWR 2012). The majority of water demands surrounds the historical park with high potential for future additional water demands (ADWR 2012).

Mexico has full legal rights to retain effluent that currently flows through the historical park, which

Table 16. Summary of hydrology indicators, measures, and condition rationale.

Indicators	Measures	Condition/Trend/ Confidence	Rationale for Condition
Groundwater	Depth to Groundwater		Depth to groundwater at all three wells indicate sufficient water levels to maintain mature cottonwood and willow trees. None of the well data indicate sufficient water levels for juveniles of either species. Because of some issues with data quality, confidence in the condition rating of moderate/significant concern is medium. Trend data indicate slight improvements in depth to groundwater, but the defect in the deep well casing may have influenced trends. Therefore, trends are unknown.
Surface Water Quantity	Number of No-Flow Events		There were 20 no-flow events lasting anywhere from one to 53 days from WYs 1995 to 2017. Although there were 0 no-flow events in WYs 2015-2017, the prevalence of no-flow events over the period of record indicates moderate/significant concern. The high variability in data precluded trend analysis. Confidence in the condition rating is high. These data provide conservative estimates of no-flow events.
	Number of 50-year or Greater Flow Events		There were no 50-year or greater flood events during WYs 1996 to 2016. Therefore, the condition is good. Trend is unchanging and confidence is high.
	Number of Bankfull Events		The number of bankfull events ranged from none to a minimum of two per WY from 1996 to 2016. However, for five of the nine WYs in which bankfull events occurred, we could not determine whether there was more than one bankfull event because only some years were summarized by instantaneous flows greater than 2,330 cfs. For the remaining 15 years, the reference condition of no more than 2 bankfull events was not exceeded. Therefore, the condition is good but confidence is low and trend is unknown because of the five years for which the total number of bankfull events is unknown.
	Change in Mean Annual Discharge		There was no trend in mean annual discharge from WYs 1996 to 2017; however, from 2005 to 2012 there was an obvious decline in discharge. Discharge then increased in 2014, declined for two years, and then peaked in 2017. Seasonal data show an overall decline in total discharge for spring, summer, and winter but not during the monsoon season. These results warrant moderate/significant concern. Confidence in the condition rating is high.
Stream Channel Geomorphology	Sinuosity		Reference conditions were based on change over time, and only one sample has been collected to date. Those data were not available for this assessment. Therefore, the condition is unknown, trend could not be determined, and confidence is low due to the unknown condition.
	Cross-sectional Area		Reference conditions were based on change over time, and only one sample has been collected to date. Those data were not available for this assessment. Therefore, the condition is unknown, trend could not be determined, and confidence is low due to the unknown condition.
	Dominant Particle Size		The dominant particle size in WY 2011 and WY 2016 was sand followed by gravel. Annual data for WYs 2012-2015 were not available. The dominant particle size averaged over WYs 2012-2015 indicate that the reach was dominated by gravel followed by sand. Although the dominant particle size appears to be similar over time, the confidence is medium due to lack of reported data. Trend could not be determined.

Table 16 continued. ***Summary of hydrology indicators, measures, and condition rationale.***

Indicators	Measures	Condition/Trend/ Confidence	Rationale for Condition
Stream Channel Geomorphology *continued*	Particle Size Assessment		Sand dominated the index reach during WY 2011 and 2016, with a particle size <2.8 mm (0.1 in). In 2011, the median particle size in riffle habitat was 11 mm (0.4 in) and 16 mm (0.6 in) in 2016. While similar, we could not make a reliable comparison without more data. Data for WYs 2012-2015 were not available. Therefore, the condition appears good, but confidence is medium and trend is unknown.
Overall Condition	Summary of All Measures		Although four of the seven measures for which condition was determined were rated as good, low depth-to-groundwater levels; the prevalence of no-flow events; and declines in discharge during winter, spring, and summer, warrant an overall condition rating of moderate/significant concern. Furthermore, two of the measures rated as good had low confidence, and measures with low confidence contribute less to the overall condition rating.

amounts to more than two-thirds of the annual volume of water in the Upper Santa Cruz River (Brewer and Fabritz-Whitney 2012). In 2009, the Nogales International Wastewater Treatment Plant upgraded their system with positive effects on water quality (Zugmeyer 2016). In 2013, the construction of a new wastewater treatment plant in Nogales, Sonora, Mexico diverted some of this effluence back into Mexico (Zugmeyer 2016). The increase in uncertainty regarding climate impacts on water resources further complicates water management in the Santa Cruz watershed. Since 2000, southern Arizona has been in drought conditions, but since WY 2014, precipitation has been at or above the 36-year average (1981-2016) (Gwilliam et al. 2017). While precipitation in recent years has helped recharge aquifers, future climate scenarios predict higher annual frequency of summer dry seasons with more variability in winter precipitation (Shamir et al. 2015).

Sources of Expertise

Assessment author is Lisa Baril, biologist and science writer, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Water Quality

Background and Importance

The headwaters of the Santa Cruz River are located in the San Rafael Valley, which is southeast of Tumacácori National Historical Park (NHP) (Brewer and Fabrtiz-Whitney 2012). The river then flows south into Mexico before meandering north and back into the U.S. Approximately, 16 km (10 mi) from the U.S.-Mexico border, the Santa Cruz River flows through the historical park and eventually connects with the Gila River south of Phoenix, Arizona (Brewer and Fabrtiz-Whitney 2012). The Santa Cruz River historically flowed perennially from its headwaters to Tubac, Arizona just north of Tumacácori NHP (Wood et al. 1999). By the 1940s, however, extensive groundwater pumping for agriculture and other uses reduced natural flows in the river. Perennial flows were restored in the 1970s with reclaimed water from the Nogales International Wastewater Treatment Plant (NIWTP).

The NIWTP, along the U.S.-Mexico border, treats water from both countries. While perennial flows were restored, water quality was impaired in this effluent-dependent system (Zugmeyer 2016). In 2009, however, the NIWTP was upgraded and water quality improved with positive effects for downstream riparian vegetation and wildlife (Zugmeyer 2016). In 2013, a new wastewater treatment plant was constructed in the city of Nogales in the Mexican State of Sonora. With the completion of the plant, some of the water that had been discharged into the Santa Cruz River is now diverted back into Mexico for agricultural and other uses (Zugmeyer 2016). Once again, flows in the Santa Cruz River have declined, probably through a combination of reduced effluent, drought, and increased infiltration with improved water quality (Zugmeyer 2016).

This assessment focuses on water quality, which includes measures of the chemical and biological properties of aquatic systems. Aquatic ecosystems depend on the maintenance of these properties within a certain range in order to sustain life-supporting biochemical processes in plant and animal communities. Water quality was identified as an important vital sign for monitoring at select Sonoran Desert Network (SODN) parks, including at Tumacácori NHP (Mau-Crimmins et al. 2005).

Data and Methods

To assess the current condition of water resources in Tumacácori NHP, we used six indicators, which were chosen to be consistent with the SODN's monitoring objectives (Gwilliam et al. 2014a, 2016, and 2017). The indicators include: core water quality, metals and metalloids, nutrients, microbiological organisms,

Warning against swimming in the Santa Cruz River at Tumacácori NHP. Photo Credit: NPS.

inorganics and general water quality, and benthic macroinvertebrates.

Water quality samples were collected at the Santa Gertrudis index reach located in the historical park (see Gwilliam et al. 2014a for a map of the location). Water samples were collected once during each season from water years (WY, 1 October-30 September) 2011 through 2017; however, not all water quality measures were tested in each season. Because SODN's stream sampling protocol has not been published, we did not provide specific sampling details. Instead, we provided a brief summary of each measure and its significance. Although SODN collects many additional water quality measures, we only included those that were associated with water quality standards as defined by State of Arizona, the U. S. Environmental Protection Agency (USEPA), or SODN.

The core water quality indicator included two measures: pH and dissolved oxygen. The pH of water determines the solubility and biological availability of compounds and minerals to organisms. The amount of dissolved materials, including heavy metals, rises with increasing acidity. Therefore, pH is a good indicator of change in water chemistry and pollution (USGS 2016b). Dissolved oxygen measures the amount of gaseous oxygen (O2) dissolved in water body sampled (USGS 2016b). Because oxygen is required for fish and other aquatic organisms, low dissolved oxygen levels may put aquatic wildlife under stress. Even though oxygen may be present, levels may be so low that they are unable to sustain some aquatic species. There are many natural causes of variability in dissolved oxygen levels, including nutrient levels, groundwater input, and the time of day (USGS 2016b).

The metals and metalloids indicator included lead, selenium, iron, nickel, cadmium and others for a total of 28 measures, some of which were the dissolved form of the metal. In high concentrations metals cause major disruption of aquatic ecosystems by lowering reproductive success, interfering with normal growth and development, and, in extreme cases, causing mortality. The Upper Santa Cruz River is exposed to metals through numerous sources, including mine drainage, runoff from impervious surfaces (e.g., roadways), industrial wastewater discharge, and from the erosion of metals naturally occurring in near-surface rock strata and sediments. Most of these contaminants accumulate in aquatic food webs and may pose long-term threats to all organisms in the aquatic environment. A total of 28 metals and metalloids were included in this assessment.

The nutrients indicator is comprised of three measures: nitrate, nitrite, and ammonia. Nitrogen is essential for wildlife and plants, but excess nitrogen from agricultural practices and pollution can cause overgrowth of aquatic plants and algae (USGS 2016b). While nitrogen occurs naturally in the environment, it can also be limiting in certain environments. Maintaining a healthy balance is critical to ecological function (USGS 2016b). Three measures of nitrogen were included: Nitrate-N, Nitrite-N, and ammonia-N.

SODN uses one measure of the microbiological organisms indicator—*Escherichia coli* (*E. coli*). E. coli is one of the main species of bacteria living in the lower intestines of mammals, and its presence in water is an indication of fecal contamination (USGS 2016b). E. coli serves as a proxy for organic pollution, providing an early warning of potential risks to aquatic and terrestrial biota. E. coli is typically reported in cfu, or colony forming units.

The inorganics indicator included one measure—fluoride. Fluoride occurs naturally in water bodies but is also added to municipal water supplies (NPS 2016b). In high levels, fluoride ions can act as enzymatic poisons, inhibit enzyme activity, and interrupt metabolic processes in aquatic invertebrates and fish (Camargo 2003).

Finally, SODN uses two measures of the benthic macroinvertebrate indicator. The indices are: the Arizona Index of Biological Integrity (AZIBI) and the USEPA multi-metric index. The values produced by these two indices are the sum of scores for richness, composition, diversity, feeding groups, and pollution tolerance (ADEQ 2015, Stoddard et al. 2005). Both indices range on a scale from 0 to 100 of increasing water quality. These two indices of benthic macroinvertebrate are commonly used as indicators of water quality in Arizona because benthic macroinvertebrates are easy to collect and differ in their tolerances to pollution in relatively predictable ways. Thus, these two indices serve as a proxy for water pollution USEPA (2017d).

Reference Conditions

Each measure was assigned a reference condition of good, moderate concern, or significant concern based on the criteria presented in Table 17. Reference conditions for nearly all measures were adopted from water quality standards developed by the State of Arizona (ADEQ 2009) as reported in Gwilliam et al. (2014). The State of Arizona has identified three beneficial uses for the Santa Cruz River at Tumacácori NHP: aquatic and wildlife effluent-dependent water (A&W), partial-body contact recreational use (PBC), and agricultural livestock watering (L) (Gwilliam et

Table 17. Reference conditions used to assess water quality.

Indicators	Measures	Good	Moderate Concern	Significant Concern	Benefical Use
Core Water Quality	pH (SU)	6.5 to 9.0	–	< 6.5 or > 9.0	A&W
	Dissolved Oxygen (mg/L)	>3	–	≤3	A&W
Metals and Metalloids	Antimony (mg/L)	<0.747	–	≥0.747	PBC
	Dissolved Antimony (mg/L)	<0.60	–	≥0.60	A&W
	Arsenic (mg/L)	<0.20	–	≥2.0	L
	Dissolved Arsenic (mg/L)	<0.15	–	≥0.15	A&W
	Barium (mg/L)	<98	–	≥98	PBC
	Beryllium (mg/L)	<1.867	–	≥1.867	PBC
	Boron (mg/L)	<186.667	–	≥186.667	PBC
	Cadmium (mg/L)	<0.050	–	≥0.050	L
	Dissolved Cadmium	<0.00091-0.0010	–	≥0.0010	A&W
	Chromium (mg/L)	<1.0	–	≥1.0	L
	Copper (mg/L)	<0.50	–	≥0.50	L
	Dissolved Copper (mg/L)	<0.016-0.019	–	≥0.019	A&W
	Dissolved Iron (mg/L)	<1.0	–	≥1.0	A&W
	Lead (mg/L)	<0.015	–	≥0.015	PBC
	Dissolved Lead (mg/L)	<0.0053-0.0064	–	≥0.0064	A&W
	Manganese (mg/L)	<130.667	–	≥130.667	PBC
	Mercury (mg/L)	<0.010	–	≥0.010	L
	Dissolved Mercury (mg/L)	<0.000010	–	≥0.000010	A&W
	Nickel (mg/L)	<28	–	≥28	PBC
	Dissolved Nickel (mg/L)	<0.093-0.110	–	≥0.110	A&W
	Selenium (mg/L)	<0.002	–	≥0.002	A&W
	Silver (mg/L)	<0.004667	–	≥0.004667	PBC
	Dissolved Silver (mg/L)	<0.011-0.015	–	≥0.015	A&W
	Thallium (mg/L)	<0.075	–	≥0.075	PBC
	Dissolved Thalium (mg/L)	<0.15	–	≥0.15	A&W
	Uranium (mg/L)	<2.8	–	≥2.8	PBC
	Zinc (mg/L)	<25	–	≥25	L
	Dissolved Zinc (mg/L)	<0.21-0.25	–	≥0.25	A&W
Nutrients	Nitrate-N (mg/L)	<3,733.333	–	≥3,733.333	PBC
	Nitrite-N (mg/L)	<233.333	–	≥233.333	PBC
	Ammonia-N (mg/L)	<0.51-1.28	–	≥1.28	A&W
Microbiological Organisms	*E. coli* (cfu/100ml)	<575	–	≥575	PBC
Inorganics	Fluoride (mg/L)	<140	–	≥140	PBC
Benthic Macroinvertebrates	Arizona Index of Biological Integrity	≥50	40-49	≤39	Warm Water
	EPA Multi-metric Index	≥56	47-56	<47	Xeric Habitat

* A&W: aquatic and wildlife effluent-dependent water; L: agricultural and livestock watering; PBC: partial body contact recreational use.

al. 2014a). Criteria differ depending on whether the measure is acute (occurring over a short time) or chronic (occurring over months or longer). Although samples collected by SODN were single grab samples, SODN used the chronic criteria, which are more stringent than acute criteria (Gwilliam et al. 2014a). The more stringent criteria serve as an early warning sign of potential water quality issues.

Reference conditions for the AZIBI were based on "warm water" habitat (ADEQ 2015), and USEPA multi-metric index reference conditions were based on "xeric" habitat (Stoddard et al. 2005). For the AZIBI, the "meeting" criteria described by the ADEQ corresponds to good condition, the "inconclusive" criteria corresponds to moderate concern condition, and the "violating" criteria corresponds to significant concern condition. For the USEPA multi-metric index, "least disturbed" corresponds to good, "intermediate" corresponds to moderate concern, and "most disturbed" corresponds to significant concern in this assessment.

Condition and Trend

For each water year, 90-91 discrete water sample analyses were associated with numerical reference conditions. Of these, the vast majority (>97%) were within Arizona State water quality standards (Table 18). There were no non-attaining samples during WY 2015. Of the remaining years, only one or two water samples did not meet reference conditions. For all measures, trends were evaluated based on the condition rating for each WY. For example, if pH met the state criteria for good condition in all WYs, we considered the trend to be unchanging. We did not report or evaluate specific values because reference conditions were based on whether samples met or exceeded the criteria.

Table 18. Water quality measures not attained in the Santa Cruz River.

Water Year	# Samples with Criteria	# Non-attaining Samples	% of Compliant Samples	Measure
2011	91	2	97.8	*E. coli*
2012	91	2	97.8	Dissolved Lead, Lead
2013	91	2	97.8	*E. coli*, Dissolved Lead
2014	91	2	97.8	*E. coli*
2015	90	0	100	None
2016	91	1	98.9	*E. coli*
2017	91	1	98.9	*E. coli*

Source: Data were provided by E. Gwilliam, SODN aquatic ecologist.

All core water samples tested for pH and dissolved oxygen met state standards; therefore, the condition for these two measures is good. The trend appears unchanging based on the persistence of the good condition rating for each season and year sampled. Confidence in the condition rating is high.

Of the 28 metals and metalloids tested in the Santa Cruz River only two (lead and dissolved lead) exceeded reference conditions. Reference conditions for both measures were exceeded in 2012, while in 2013, only dissolved lead was found in exceedence (Table 18). Although the measures did not meet state standards in these two years, the other five years were compliant. Therefore, the condition for lead, and dissolved lead warrants moderate concern. Confidence in the condition rating is medium because of uncertainties regarding the source of lead and how frequently it actually occurs. We did not assign a trend for this measure. Conditions for the remaining measures are good. Trend appears unchanging based on the persistence of the good condition rating for each season and year sampled. We did not evaluate trend in actual values. Confidence in the condition rating is high for all measures except for lead and dissolved lead as previously stated.

For the nutrients indicator, all samples tested for the three measures of nitrogen met state standards; therefore, the condition is good. Trend appears unchanging based on the persistence of the good condition rating for each season and year sampled. Confidence in the condition rating is high.

For the single measure of the microbiological organisms indicator, water samples exceeded *E. coli* reference conditions during WYs 2011, 2013, 2014, 2016, and 2017 (Table 18). These data warrant a significant concern condition rating. The trend is unchanging since *E. coli* was persistent over time even though only a handful of samples tested positive over all years sampled. We did not evaluate trend in actual values. It is likely, however, that *E. coli* exceeded standards more often than what was captured during sampling efforts (Gwilliam et al. 2014a, Gwilliam et al. 2016, Gwilliam et al. 2017). Confidence in the condition rating is high. Exceedences were likely in response to stormwater runoff.

For the inorganics indicator, none of the samples tested for fluoride exceeded state standards. The condition is good. Trend appears unchanging based on the persistence of the good condition rating for each season and year sampled. Confidence in the condition rating is high.

For the benthic macroinvertebrates indicator, the mean AZIBI was 35.9, while the mean USEPA multi-metric index was 18.0 (Table 19). The mean value for the AZIBI fell within the significant concern condition rating. The mean values for each index fell within the significant concern condition rating. Neither the AZIBI ($n = 6$, $t = 1.0$, $p = 0.37$) nor the USEPA multi-metric index ($n = 6$, $t = 0.5$, $p = 0.67$) showed a significant trend over time. These results warrant significant concern with unchanging trends. Confidence in the condition ratings are high.

Overall Condition, Threats, and Data Gaps

Table 20 summarizes the condition rating and rationale used for each indicator and measure. Nearly all measures included in this assessment were in good condition. Of the hundreds of samples obtained over the seven water years, only three measures (lead, dissolved lead, and *E. coli*) exceeded state standards. Of the samples collected, relatively few samples were not compliant. Although the overwhelming majority of measures indicate good condition, there are a few specific concerns, including *E. coli,* lead, and low indices of benthic macroinvertebrates. For these reasons, the condition of water quality warrants moderate concern. Confidence is high due to the seven years of sampling. As a result, the majority of measures were assigned high confidence. Measures with high confidence are generally given more weight

Table 19. Indices of benthic macroinvertebrates.

Water Year	AZIBI	USEPA Multi-metric Index
2012	27.1	17.9
2013	33.8	17.7
2014	40.8	17.9
2015	43.5	12.8
2016	34.8	23.6
2017	35.6	18.3
Mean	35.9	18.0

Source: Data were provided by E. Gwilliam, SODN aquatic ecologist.

than measures with low or medium confidence. No measures were assigned low confidence.

The overall trend is unchanging. As previously stated, we did not evaluate trend in actual values. Trend was based on seasonal and annual condition ratings for all measures. An analysis of trends in actual values over time, however, may indicate emerging concerns. A key uncertainty is the source of lead in park waters. Although there are natural sources of lead in the environment, this element can also enter the aquatic system through industry, waste management, sewage systems, and fishing tackle (NPS 2016b). The data presented in this assessments suggest that the presence of lead is a rare occurrence, but given the consequences of lead for human health, aquatic wildlife, and plants, we assigned moderate concern for these measures. Lead was highlighted as a data gap in the 2016 ADEQ water quality assessment report for the Upper Santa Cruz watershed (ADEQ 2016a).

The Upper Santa Cruz watershed, which includes Tumacácori NHP, was considered impaired for *E. coli* and ammonia by the State of Arizona in 2010 (ADEQ 2016a). In 2016, however, this reach was not listed as impaired for either measure, but the upstream reach from the NIWTP to Josephine Canyon is currently listed as impaired for *E. coli* (ADEQ 2016b). The wastewater treatment plant removes *E. coli* before releasing effluent into the river, so likely sources include human waste, livestock, and wildlife (Zugmeyer 2016). Although only a few samples exceeded *E. coli* state standards at the historical park's sampling site, Gwilliam et al. (2014, 2016, and 2017) speculate that *E. coli* probably exceeded standards more often than what sampling captured. *E. coli* exceedences primarily occur during the rainy seasons with stormwater runoff (Zugmeyer 2016). All other measures included in this assessment were within state limits, but SODN gathers data for many other measures that do not have state standards, and these elements, compounds, and chemicals may also affect water quality.

In 2012, SODN began collecting data on contaminants of emerging concern, which include pesticides, personal care products, and pharmaceuticals (Gwilliam 2013). During WYs 2012 through 2014, eight industrial organic compounds, two organic compounds, eight pesticides, and 44 pharmaceuticals were detected in water samples collected in the Santa Gertrudis index reach (SODN unpublished data provided by K.

Table 20. Summary of water quality indicators, measures, and condition rationale.

Indicators	Measures	Condition/Trend/Confidence	Rationale for Condition
Core Water Quality	pH (SU)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Dissolved Oxygen (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
Metals and Metalloids	Antimony (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Dissolved Antimony (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Arsenic (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Dissolved Arsenic (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Barium (mg/L)		Most samples attained Arizona State criteria, but several exceeded state standards in 2011 and 2013. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Beryllium (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Boron (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Cadmium (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Dissolved Cadmium		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Chromium (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Copper (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.

Table 20 continued. ***Summary of water quality indicators, measures, and condition rationale.***

Indicators	Measures	Condition/Trend/Confidence	Rationale for Condition
Metals and Metalloids *continued*	Dissolved Copper (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Dissolved Iron (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Lead (mg/L)		Only one sample in 2012 exceeded state standards, which is why this measure was assigned moderate concern but with medium confidence in the rating. Trend could not be determined.
	Dissolved Lead (mg/L)		Only three samples in 2012 and 2013 exceeded state standards, which is why this measure was assigned moderate concern but with medium confidence in the rating. Trend could not be determined.
	Manganese (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Mercury (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Dissolved Mercury (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Nickel (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Dissolved Nickel (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Selenium (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Silver (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Dissolved Silver (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Thallium (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.

Table 20 continued. ***Summary of water quality indicators, measures, and condition rationale.***

Indicators	Measures	Condition/Trend/Confidence	Rationale for Condition
Metals and Metalloids *continued*	Dissolved Thalium (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Uranium (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Zinc (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Dissolved Zinc (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
Nutrients	Nitrate-N (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Nitrite-N (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
	Ammonia-N (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
Inorganics	Fluoride (mg/L)		All samples attained Arizona State criteria. Confidence is high due to the seven years of sampling and multiple annual sampling periods. The trend is unchanging based on the annual condition rating.
Microbiological Organisms	*E. coli* (cfu/100 ml)		Although relatively few samples tested positive for *E. coli*, this bacterium was persistent over time occurring in five of the seven years. Trend is unchanging. Confidence is high.
Benthic Macroinvertebrates	Arizona Index of Biological Integrity		Four of the six years warrant significant concern and two years warrant moderate concern. Over all years, the trend appears unchanging but well below values that indicate good water quality.
	USEPA Multi-metric Index		All years were well below the significant concern threshold and indicate an impaired system. Trend is unchanging. Confidence is high due to the six years of sampling.
Overall Condition	Summary of All Measures		Although the overwhelming majority of measures indicate good condition, there are a few specific concerns including persistent state standard exceedances of *E. coli,* occasional lead exceedances, and persistent low indices of benthic macroinvertebrates. For these reasons, the condition of water quality warrants moderate concern. Confidence is high due to the seven years of sampling and numerous measurements collected annually. Overall trend is unchanging based on the consistency of condition ratings over the seven years of sampling.

Raymond). These contaminants may be responsible for low indices of benthic macroinvertebrates, which are sensitive to water quality, but physical changes in the stream bed could also be responsible (Stoddard et al. 2005).

The hydrology assessment in this report shows a significant decline in streamflow during spring, summer, and winter. Mean annual flows have declined particularly since 2005, although flows have increased since 2014. Low flows and drying of the river during May and June could concentrate water quality constituents leading to water quality issues and impacts on aquatic organisms (Gwilliam 2013).

Hundreds of water samples have been collected to monitor changes in dozens of water quality measures in the historical park. Because of this large volume of data, there are few data gaps. However, in this assessment, we did not report on or evaluate specific water quality values because reference conditions were based on whether samples met or exceeded the criteria. While this generalized assessment indicates water quality is of moderate concern, a rigorous analysis of values over time would better inform current condition.

Within the historical park, water quality is closely monitored by SODN and outside the historical park by ADEQ, the Sonoran Institute, and Friends of the Santa Cruz River. Private, state, and federal investment in the Santa Cruz River watershed increases the likelihood that water quality issues will be detected early.

Sources of Expertise

Assessment author is Lisa Baril, biologist and science writer, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Upland Vegetation and Soils

Background and Importance

The National Park Service (NPS) Sonoran Desert Inventory and Monitoring Network (SODN) monitors upland vegetation and soils across 10 of its 11 network parks, including at Tumacácori National Historical Park (NHP), to better understand current condition and patterns of change over time (Hubbard et al. 2012). Terrestrial vegetation comprises 99% of the earth's biomass, and plants are the primary producers of life on Earth (Hubbard et al. 2012). Soils and climate determine vegetation type. Monitoring vegetation and soils can help scientists recognize subtle shifts in ecosystem structure and function, such as changes in water availability, disturbances, and climatic conditions (Hubbard et al. 2012). Taking a holistic community perspective can inform underlying processes that are difficult to monitor directly, while monitoring specific species can inform changes in abundance and demography (Hubbard et al. 2012). Both aspects are important for understanding vegetation and soils dynamics.

Although Tumacácori NHP is part of SODN, the park lies east of the Sonoran Desert in the Apache Highlands ecoregion (NPS SODN 2017). The park is situated at an elevation range of approximately 994-1,097 m (3,261-3,599 ft) and lies within the thornscrub biome, which is the second driest and lowest elevation biome in the network after desert scrub (Hubbard et al. 2012). Common plant species include velvet mesquite (*Prosopis velutina*), acacias (*Acacia* spp.), and creosote bush (*Larrea tridentata*) (Hubbard et al. 2012). The effluent-driven Santa Cruz River flows through the historical park's main unit and supports cottonwood-willow (*Populus* spp.-*Salix* spp.) forests in addition to thornscrub vegetation (Gwilliam et al. 2017). Vegetation in the park's other two units are dominated by thornscrub vegetation.

According to Powell et al. (2005), soils across the park are typical of floodplains, alluvial fans, and valley slopes. Soils are well-drained and deep with high water-holding capacity (Powell et al. 2005). Tumacacori NHP experiences long, hot summers sometimes exceeding 38 °C (100 °F) in July and two distinct periods of precipitation (summer and winter) with about half of all (~ 41 cm [~16 in]) precipitation falling during July through September (Mau-Crimmins et al. 2005).

A long history of land use has significantly altered the natural vegetation in and around the historical park. In 1691, the Spanish established missions in what are now known as the Calabazas and Tumacacori units (NPS 2014a). By 1756 a third mission was established in the Calabazas Unit (NPS 2014a). The boundary of the historical park was enlarged several times since

Former agricultural fields in Tumacácori NHP. Photo Credit: NPS.

it was first established as a national monument in 1908 (NPS 2014a). In 1990 the park was redesignated as a national historical park and the boundary was enlarged again, reaching its current extent in 2002. Not only has there been a long history of human land use within the original park boundary, but in the additions as well since they were not protected until they became part of the NPS. Euro-American land use has included agriculture, livestock grazing, and clearing of mesquite-bosque and cottonwood-willow habitat (Drake et al. 2009). Even prior to the Spanish missionaries, the O'odham are thought to have inhabited the area for hundreds or even thousands of years, but the impact of the O'odham people on native vegetation is unknown (Drake et al. 2009).

Data and Methods

This assessment is based on six indicators (erosion hazard, erosion features, site resilience, fire hazard, native perennial plant community composition and structure, and non-native plants), with a total of 12 measures. These data were collected as part of SODN's upland vegetation and soils monitoring program at Tumacácori NHP. SODN's protocol employs a random, spatially balanced sampling design with plots allocated by elevation and soils strata (Hubbard et al. 2012). Because there is little topographical relief in the park, all plots were established in the same elevation strata: thornscrub. Seven plots were established in the park's main unit; two plots were established in the Guevavi Unit; and three plots were established in the Calabazas Unit. The Tumacacori, or main unit, is the largest at 131.5 ha (325 ac). The Guevavi Unit is the smallest at 2.83 ha (7.0 ac), and the Calabazas Unit is 11 ha (28 ac) (Studd and Zepp 2009).

Plots were 20 x 50-m (66 x 164 ft) with six 20 m (66 ft) transects established every 10 m (33 ft) along the plot's long edge. The transects divided the plot into five subplots. Vegetation and soils were measured in all of the following three layers: field (0-.05 m [<1.6 ft]), subcanopy (>0.5-2.0 m [1.6-6.6 ft]), and canopy (>2.0 m [6.6 ft]). All of the following measures were collected in either the subplots (measures of extent or frequency) or at 0.5 m (1.6 ft) intervals along line transects (measures of cover). Plot-level data were then averaged by unit for each round of sampling. The first round of sampling occurred from 2007 to 2009 and the second round of sampling occurred from 2013 to 2015. Plots were surveyed during July and August. Data were provided by K. Bonebrake, SODN data manager, via e-mail on 8 December 2017. For brevity, we provide a brief description of each measure and why it is important rather than specific sampling details. Further details on data collection methods are described in Hubbard et al. (2012).

The first measure of the erosion hazard indicator is bare ground cover without overhead vegetation. The amount of bare ground is a measure of erosion potential since most soil loss occurs in unprotected bare patches (Hubbard et al. 2012). As the amount of bare ground increases, the velocity of surface water flow and erosion due to wind also increases. Vegetation, soil crusts, litter, and rock cover help protect against rapid soil loss.

The second measure of erosion hazard is soil aggregate stability. Soil aggregate stability is a measure of resistance to erosion (Hubbard et al. 2012). Soil aggregate stability was classified on a scale ranging from 1 (least stable) to 6 (most stable) (Herrick et al. 2005). "Surface soil aggregates play a critical role in the movement of water, nutrients, and gases through the soil–atmosphere interface and in resisting wind and water erosion. Soil aggregate stability provides insight into current and past site disturbance and is an efficient measure of site stability in the context of potential management actions" (Hubbard et al. 2012).

For the erosion feature type indicator there is only one measure: the extent of area affected by a particular feature type. The extent of affected area by feature type was surveyed as described in Nauman (2011):

> Erosion features were described using a semi-quantitative scheme to estimate approximate extent (%) of affected areas [in each plot]. Estimated erosion classes were as follows: 0%, 1–5%, 6–25%, 26–50%, 51–75%, and >75%. Recorded features included tunneling, sheeting, rilling, gullying, pedestal development, terracette occurrence, and burrowing activity. Sheet, rill, and gully features are direct indicators of erosion, while the other features are precursors to water erosion or signs of susceptibility. Erosion observations were used to indicate site stability and help identify any other measured features that might be associated with increased erosion.

There are two measures of site stability (foliar cover of dead perennial plants in the field layer and in the subcanopy layer), which we consider together for simplicity. These two measures address resilience, or the ability of plant communities to recover after a disturbance, maintain natural processes, and resist invasion by non-native plants. Dead plants included only those that were still rooted in the ground (Hubbard et al. 2012). Low levels of dead plants indicate higher site resilience, especially if dead cover declines rapidly following a disturbance.

SODN uses grass and forb cover as one measure of fire hazard in thornscrub. Thornscrub vegetation is not fire-adapted (Hubbard et al. 2012). Historically, fires were rare in this habitat type because of the low accumulation of fine fuels, such as grasses and forbs. Introduced species, however, are often tolerant of or even thrive after a fire. This creates a positive feedback loop whereby non-native grasses invade causing increased fire frequency, which then results in greater spread of non-native species followed by more widespread fires (Hubbard et al. 2012). Determining the amount of accumulated fine fuels (e.g., forbs and grasses) informs fire hazard.

SODN also uses the ratio of annuals to total plant cover as a measure of fire hazard in thornscrub. In years of high precipitation, annuals may fill in the spaces between perennials creating a continuous source of fuels (Rao et al. 2015). Non-native annual grasses, such as Lehman lovegrass (*Eragrostis lehmanniana*), are particularly problematic. Furthermore, biomass of annual grasses tend to persist longer than annual forbs (Rao et al. 2015).

The native perennial plant community composition and structure indicator is comprised of two measures—cover of common species and frequency of uncommon species. The first measure is an effective approach for monitoring plant populations as a whole as well as trends in individual species, especially keystone species (Hubbard et al. 2012). Monitoring cover for a suite of species allows for changes in future management direction (Hubbard et al. 2012). Common species were considered perennials exhibiting >10% absolute canopy cover, including non-native plants and all plant lifeforms (e.g., trees, shrubs, forbs) (Hubbard et al. 2012). We included non-native plant cover for both annuals and perennials under the non-native plants indicator. The frequency of uncommon species provides an index of change over time and space (Hubbard et al. 2012). It is useful for species that are uncommon or have high year-to-year variability in occurrence (Hubbard et al. 2012). Frequency for uncommon species were perennials exhibiting <10% absolute canopy cover, including non-native plants (Hubbard et al. 2012).

The last indicator (non-native plants) consists of three measures. The first measure is extent and refers to the frequency of non-native plants encountered across monitoring plots (Hubbard et al. 2012). It is an effective way to monitor changes in the spread of non-native plants over time. The second measure is cover, which is the area over which a species or group of plants occurs. It is useful for monitoring which species are dominant in a particular site. The third measure is the ratio of non-native cover to total cover. This measure is useful for determining what proportion of the total plant cover is composed of non-native species and, like total cover, is useful for determining dominance.

Reference Conditions

Reference conditions are described for resources in good and moderate/significant concern conditions for each of the 12 measures (Table 21). Reference conditions were based on Management Assessment Points (MAPS) developed by SODN for Montezuma Castle National Monument (NM) (McIntyre et al. 2014). MAPS “represent preselected points along a continuum of resource-indicator values where scientists and managers have together agreed that they want to stop and assess the status or trend of a resource relative to program goals, natural variation, or potential concerns” (Bennetts et al. 2007). MAPS do not define management goals or thresholds. Rather, MAPS “serve as a potential early warning system,” where managers may consider possible actions and options (Bennetts et al. 2007). We used MAPs developed for Montezuma Castle NM because no MAPs have been developed specifically for Tumacácori NHP, but both units are within the thornscrub biome. MAPS were developed for all measures except for the measure of erosion features and the two measures of plant community composition and structure. However, those measures were cited as objectives in Nauman (2011) and Hubbard et al. (2012).

Table 21. Reference conditions used to assess upland vegetation and soils in Tumacácori NHP.

Indicators	Measures	Good	Moderate/Significant Concern
Erosion Hazard	Bare Ground Cover	Bare ground with no overhead vegetation is ≤ 20%.	Bare ground with no overhead vegetation is > 20%
	Soil Aggregate Stability	Average surface soil aggregate stability is ≥ Class 3.	Average surface soil aggregate stability is < Class 3.
Erosion Features	Extent of Area by Erosion Feature Type	No reference conditions established.	No reference conditions established.
Site Resilience	Foliar Cover of Dead Perennial Plants (field layer)	Foliar cover of dead perennial plants is ≤ 15%.	Foliar cover of dead perennial plants is > 15%.
	Foliar Cover of Dead Perennial Plants (subcanopy layer)	Foliar cover of dead perennial plants is ≤ 15%.	Foliar cover of dead perennial plants is > 15%.
Fire Hazard	Grass and Forb Cover (field layer)	Grass and forb cover is ≤ 30%.	Grass and forb cover is > 30%.
	Ratio of Annual Plant Cover to Total Plant Cover (field layer)	Annual plant cover: total plant cover is ≤ 1:4 (≤ 25%).	Annual plant cover: total plant cover is > 1:4 (> 25%).
Native Perennial Plant Community Composition and Structure	Cover of Common Species (all layers)	No reference conditions established.	No reference conditions established.
	Frequency of Uncommon Species	No reference conditions established.	No reference conditions established.
Non-native Plants	Extent	Extent of non-native plants is ≤ 50%.	Extent of non-native plants is > 50%.
	Total Cover (field)	Total cover of non-native plants is ≤ 10%.	Total cover of non-native plants is > 10%.
	Ratio of Non-native Plant Cover to Total Plant Cover (field layer)	Non-native plant cover: total plant cover is ≤ 1:4 (≤ 25%).	Percent of total plant cover that is non-native is > 1:4 (> 25%).

Source: McIntyre et al. (2014).

Condition and Trend

For all of the following 12 measures, differences between rounds of sampling were only highlighted if the data between the two rounds resulted in different condition ratings. There were not sufficient data to assess trends in all of the following measures since only two rounds of data have been collected as of the writing of this assessment. Therefore, trend is unknown for all measures.

Bare ground cover (a measure of erosion hazard) ranged from 3.54% to 9.59% across units and sampling periods (Table 22). All measurements averaged less than the 20% MAP, which indicates good condition for this measure. Confidence in the condition rating is high.

Soil aggregate stability (a measure of erosion hazard) exceeded class 3 (somewhat unstable) for all but one sample, which averaged 1.67 (Table 22). Overall however, these data indicate good condition across the NHP, but there may be some concerns regarding soil stability in the Calabazas Unit. Confidence in the condition rating is high.

Extent of affected area by erosion feature type suggests relatively low erosion across the three park units, at least in the plots surveyed (Tables 23 and 24). The

Table 22. Measures of erosion hazard in Tumacácori NHP.

Unit	Measures	Round 1 Mean (SE)	Round 2 Mean (SE)
Tumacácori	Bare Ground Cover (%)	3.69 (1.68)	7.92 (2.64)
	Soil Aggregate Stability (Class)	4.83 (0.29)	3.04 (0.68)
Guevavi	Bare Ground Cover (%)	3.54 (0.21)	9.59 (2.09)
	Soil Aggregate Stability (Class)	4.66 (0.29)	4.58 (0.31)
Calabazas	Bare Ground Cover (%)	8.47 (1.81)	3.89 (1.77)
	Soil Aggregate Stability (Class)	4.17 (0.60)	1.67 (0.29)

Table 23. Erosion area class by feature type as observed during round 1 in Tumacácori NHP.

Unit	Plot	Tunneling (% of plot)	Pedestals (% of plot)	Terracettes (% of plot)	Burrowing (% of plot)	Sheet (% of plot)	Rill (% of plot)	Gully (% of plot)	Estimated Degraded Area (% of plot)
Tumacácori	201_001	–	–	–	–	–	–	–	–
	201_004	0	0	0	0	0	0	0	0
	201-013	0	0	0	<5	0	0	0	0
	201_016	–	–	–	–	–	–	–	–
	201_032A	–	–	–	–	–	–	–	–
	201_AG1	–	–	–	–	–	–	–	–
	201_BOSQ1	–	–	–	–	–	–	–	–
Guevavi	201_001	0	0	0	<5	0	<5	0	2.5
	201-004	0	0	0	6-25	0	0	0	0
Calabazas	201_001	0	0	0	<5	0	0	0	0
	201_002	0	0	0	0	0	<5	0	2.5
	201_003	0	0	0	<5	0	<5	0	2.5

Note: The estimated degraded area was calculated by summing the mid-points of sheet, rill, and gully erosion.

Table 24. Erosion area class by feature type as observed during round 2 in Tumacácori NHP.

Unit	Plot	Tunneling (% of plot)	Pedestals (% of plot)	Terracettes (% of plot)	Burrowing (% of plot)	Sheet (% of plot)	Rill (% of plot)	Gully (% of plot)	Estimated Degraded Area (% of plot)
Tumacácori	201_001	0	0	0	<5	0	0	0	0
	201_004	0	0	0	<5	0	0	0	0
	201-013	0	0	0	<5	0	0	0	0
	201_016	0	0	0	0	0	0	0	0
	201_032A	0	0	0	<5	0	0	0	0
	201_AG1	0	0	0	0	0	0	0	0
	201_BOSQ1	0	0	0	0	0	0	0	0
Guevavi	200_01	0	0	0	<5	<5	0	0	2.5
	200_04	0	0	0	<5	0	0	0	0
Calabazas	201_001	0	0	0	<5	0	0	0	0
	201_002	0	0	0	<5	0	<5	0	2.5
	201_003	0	0	0	<5	0	<5	0	2.5

Note: The estimated degraded area was calculated by summing the mid-points of sheet, rill, and gully erosion.

estimated degraded area for all plots was similar across the two sampling periods. Furthermore, there was no evidence of tunneling, pedestals, or terracettes in any of the plots during either time period, but burrowing was recorded in most plots during both time periods. Burrowing is a precursor to erosion and may lead to actual erosion (sheet, rill, gully) in the future. Nevertheless, the overall degraded area across the three units was low (~2.5%). No reference conditions were established for this measure so the condition is unknown. Confidence in the condition rating is low because of the unknown condition.

The two measures of the site resilience indicator are in good condition. Foliar cover of dead perennial plants in the field layer was substantially lower during round 2 than during round 1 in all three units (Table 25). During round 1 values approached the MAP of 15% in the Tumacácori and Calabazas units and exceeded the MAP in the Guevavi Unit. However, only this measurement exceeded the MAP. Foliar cover of dead perennial plants in the subcanopy did not exceed 3% in the three park units (Table 25). Confidence in the condition rating is high for both measures.

Table 25. Measures of site resilience in Tumacácori NHP.

Unit	Measures	Round 1 % Mean (SE)	Round 2 % Mean (SE)
Tumacácori	Foliar Cover of Dead Plants (field)	12.50 (3.42)	0.78 (0.39)
	Foliar Cover of Dead Perennial Plants (subcanopy)	0.60 (0.43)	2.02 (0.96)
Guevavi	Foliar Cover of Dead Plants (field)	19.17 (2.92)	0.63 (0.63)
	Foliar Cover of Dead Perennial Plants (subcanopy)	0.63 (0.63)	2.09 (2.09)
Calabazas	Foliar Cover of Dead Plants (field)	13.19 (5.51)	0.42 (0.24)
	Foliar Cover of Dead Perennial Plants (subcanopy)	1.11 (0.37)	0.55 (0.28)

Grass and forb cover (a measure of fire hazard) exceeded the 30% MAP in all three park units except in round 1 of the Calabazas Unit; however, this value (~25%) approached the MAP and was substantially higher during round 2 (~70%) as a result of higher annual forbs and, to a lesser extent, annual grasses (Table 26). Since percent cover was greater than 30% for most measurements, this measure of fire hazard warrants moderate/significant concern. Confidence in the condition rating is high.

The proportion of total cover represented by annuals (a measure of fire hazard) was double, or nearly double, the 25% MAP for all park units and sampling period (Table 26). Given the large margins of error relative to the values however, differences between time periods may not be significant. The condition for this measure of fire hazard warrants moderate/significant concern. Confidence in the condition rating is high.

The following three paragraphs summarize the cover of common species for the native perennial plant community composition and structure indicator. Each paragraph summarizes a different unit of the NHP.

Table 26. Measures of fire hazard in Tumacácori NHP.

Unit	Measures	Round 1 % Mean (SE)	Round 2 % Mean (SE)
Tumacácori	Grass and Forb Cover (field)	36.49 (7.20)	40.47 (7.37)
	Ratio of Annual Cover to Total Cover (field)	59.84 (9.34)	43.07 (8.13)
Guevavi	Grass and Forb Cover (field)	39.38 (7.29)	42.10 (20.00)
	Ratio of Annual Cover to Total Cover (field)	57.06 (9.58)	56.02 (7.34)
Calabazas	Grass and Forb Cover (field)	25.15 (8.54)	70.29 (11.70)
	Ratio of Annual Cover to Total Cover (field)	42.46 (22.44)	71.42 (10.64)

In the Tumacácori Unit, thirty-three perennial species or genera were encountered along line transects across all lifeforms except for succulents (Table 27). Velvet mesquite dominated the subcanopy with scattered Fremont cottonwood (*Populus fremontii*) and netleaf hackberry (*Celtis reticulata*) in the overstory. A wide variety of shrubs occurred in the subcanopy, including catclaw acacia (*Senegalia greggii*) with spidergrass (*Aristida ternipes*), sand dropseed (*Sporobolus cryptandrus*), and violet wild petunia (*Ruellia nudiflora*) in the understory. The generally low cover exhibited across lifeforms and vegetation layers reveals an open, sparse plant community that is typical of thornscrub vegetation. Note that the values for this measure does not include annuals, which would increase total cover. This applies to the two following units as well.

A photograph of soil stability monitoring equipment. Photo Credit: NPS.

Table 27. Percent cover and extent for perennial species in the Tumacácori Unit in Tumacácori NHP.

Plant Group	Species	Round 1				Round 2			
		Field %Mean (SE)	Subcanopy % Mean (SE)	Canopy % Mean (SE)	Extent (%)	Field % Mean (SE)	Subcanopy % Mean (SE)	Canopy % Mean (SE)	Extent (%)
Forbs/Herbs	*Ambrosia confertiflora (weakleaf bur ragweed)*	0.30 (0.30)	0 (0)	0 (0)	43	0 (0)	0 (0)	0 (0)	0
	Boerhavia coccinea (scarlet spiderling)	0.12 (0.12)	0 (0)	0 (0)	43	0.54 (0.28)	0 (0)	0 (0)	71
	Commicarpus scandens (climbing wartclub)	0 (0)	0 (0)	0 (0)	0	0.30 (0.20)	0.06 (0.06)	0 (0)	86
	Ruellia nudiflora (violet wild petunia)	0.12 (0.08)	0 (0)	0 (0)	43	3.69 (2.31)	0 (0)	0 (0)	57
	Talinum paniculatum (jewels of Opar)	0 (0)	0 (0)	0 (0)	0	1.25 (1.25)	0 (0)	0 (0)	29
	Tetramerium nervosum (hairy fournwort)	0.18 (0.18)	0 (0)	0 (0)	29	0 (0)	0 (0)	0 (0)	0
Graminoids	*Aristida purpurea* (purple threeawn)	1.01 (1.01)	0 (0)	0 (0)	29	0 (0)	0 (0)	0 (0)	0
	Aristida ternipes (spidergrass)	1.25 (0.84)	0.6 (0.06)	0 (0)	57	4.58 (3.83)	0 (0)	0 (0)	71
	Elymus elymoides (squirreltail)	0 (0)	0 (0)	0 (0)	0	0.18 (0.18)	0 (0)	0 (0)	29
	Leptochloa dubia (green sprangletop)	0 (0)	0 (0)	0 (0)	0	0.12 (0.12)	0 (0)	0 (0)	14
	Sporobolus cryptandrus (sand dropseed)	1.37 (0.97)	0.18 (0.18)	0 (0)	57	0.48 (0.41)	0.06 (0.06)	0 (0)	71
Shrubs/ Subshrubs	*Anisacanthus thurberi* (Thurber's desert honeysuckle)	0 (0)	0.06 (0.06)	0 (0)	29	0.24 (0.24)	0.18 (0.18)	0 (0)	43
	Baccharis sarothroides (desertbroom)	0.59 (0.47)	1.49 (0.57)	0 (0)	86	0 (0)	0.06 (0.06)	0 (0)	71
	Ceanothus greggii (desert ceanothus)	0.12 (0.12)	0.06 (0.06)	0.42 (0.42)	14	0 (0)	0 (0)	0 (0)	0
	Celtis pallida (spiny hackberry)	0 (0)	0 (0)	0 (0)	0	0.30 (0.24)	0.12 (0.12)	0 (0)	71
	Condalia correllii (Correll's snakewood)	0 (0)	0 (0)	0 (0)	0	0.06 (0.06)	0.18 (0.12)	0.30 (0.30)	29
	Condalia sp. (snakewood)	0 (0)	0 (0)	0.06 (0.06)	14	0 (0)	0 (0)	0 (0)	0
	Lycium andersonii (water jacket)	0.48 (0.41)	1.07 (0.71)	0 (0)	43	0 (0)	0 (0)	0 (0)	0
	Lycium berlandieri (Berlandier's wolfberry)	0 (0)	0 (0)	0 (0)	0	0.36 (0.25)	0.95 (0.61)	0 (0)	29
	Rivina humilis (rougeplant)	0.71 (0.31)	0 (0)	0 (0)	86	4.29 (1.73)	0.06 (0.06)	0 (0)	86
	Senegalia greggii (catclaw acacia)	1.31 (0.85)	3.81 (2.36)	3.04 (1.97)	57	1.07 (0.78)	6.67 (4.22)	6.07 (4.14)	71
	Ziziphus obtusifolia (lotebush)	0.77 (0.77)	1.55 (0.86)	0.12 (0.12)	57	0.36 (0.19)	1.31 (0.86)	0.36 (0.29)	86
Trees	*Celtis reticulata* (netleaf hackberry)	0.18 (0.08)	1.19 (0.89)	1.01 (1.01)	86	0.72 (0.43)	3.75 (2.05)	8.33 (7.45)	86

Table 27 continued. Percent cover and extent for common perennial species in the Tumacácori Unit in Tumacácori NHP.

Plant Group	Species	Round 1				Round 2			
		Field %Mean (SE)	Subcanopy % Mean (SE)	Canopy % Mean (SE)	Extent (%)	Field % Mean (SE)	Subcanopy % Mean (SE)	Canopy % Mean (SE)	Extent (%)
Trees *continued*	*Populus fremontii* (Fremont cottonwood)	0.18 (0.18)	0.12 (0.12)	2.26 (2.26)	14	0.18 (0.18)	0.42 (0.42)	2.62 (2.62)	14
	Prosopis velutina (velvet mesquite)	0.42 (0.18)	7.97 (2.71)	31.85 (11.26)	100	2.56 (1.15)	17.68 (5.76)	35.89 (10.17)	100
Vines	*Clematis drummondii* (Drummond's clematis)	0.71 (0.54)	0.12 (0.12)	0 (0)	43	0 (0)	0 (0)	0 (0)	0
	Clematis ligusticifolia (western white clematis)	0 (0)	0 (0)	0 (0)	0	0.48 (0.23)	0.18 (0.18)	0.06 (0.06)	43
	Cocculus diversifolius (snailseed)	0 (0)	0 (0)	0 (0)	0	2.14 (1.02)	1.37 (0.61)	0.42 (0.22)	71
	Cucurbita foetidissima (Missouri gourd)	0 (0)	0 (0)	0 (0)	0	0.18 (0.18)	0 (0)	0 (0)	14
	Funastrum hartwegii (Hartweg's twinevine)	0 (0)	0 (0)	0 (0)	0	0.12 (0.18)	0.18 (0.12)	0 (0)	57
	Passiflora mexicana (Mexican passionflower)	0 (0)	0 (0)	0 (0)	0	0.18 (0.18)	0 (0)	0 (0)	43
	Phaseolus ritensis (Santa Rita Mountain bean)	0.83 (0.42)	0.71 (0.38)	0.06 (0.06)	43	0 (0)	0 (0)	0 (0)	0
	Phaseolus sp. (bean)	0.12 (0.12)	0.12 (0.12)	0 (0)	14	0 (0)	0 (0)	0 (0)	0

In the Guevavi Unit, eighteen species or genera of perennial plants were encountered along line transects (Table 28). As with the Tumacácori Unit, all lifeforms except for succulents were represented. The Guevavi Unit, however, contained roughly half as many species than the Tumacácori Unit owing, in large part, to its small size. Velvet mesquite represented the only tree species with catclaw acacia and lotebush (*Ziziphus obtusifolia*) in the subcanopy and an understory of streambed bristlegrass (*Setaria leucopila*), cotta grass (*Cottea pappophoroides*), and others. As with the Tumacácori Unit, cover was moderately low for all lifeforms and vegetation layers, which is indicative of the open shrubland formations.

In the Calabazas Unit, twenty-two species or genera were observed along line transects (Table 29). Unlike the other two units, vines were absent but one species of succulent was recorded. Velvet mesquite was the only tree species, with the highest cover exhibited in the subcanopy. Whitehorn acacia (*Vachellia constricta*) was the dominant shrub species. Catclaw acacia and catclaw mimosa (*Mimosa aculeaticarpa*) were also present along with other shrub species. Bush

A photograph of a creosote bush. Photo Credit: NPS.

Table 28. Percent cover and extent for perennial species in the Guevavi Unit in Tumacácori NHP.

Plant Group	Species	Round 1				Round 2			
		Field %Mean (SE)	Subcanopy % Mean (SE)	Canopy % Mean (SE)	Extent (%)	Field % Mean (SE)	Subcanopy % Mean (SE)	Canopy % Mean (SE)	Extent (%)
Forbs/Herbs	*Boerhavia coccinea (scarlet spiderling)*	0 (0)	0 (0)	0 (0)	0	0.84 (0.84)	0 (0)	0 (0)	50
	Commicarpus scandens (climbing wartclub)	0 (0)	0 (0)	0 (0)	0	0.21 (0.21)	0 (0)	0 (0)	50
Graminoids	*Aristida purpurea* (purple threeawn)	1.67 (1.67)	0 (0)	0 (0)	50	0 (0)	0 (0)	0 (0)	0
	Bouteloua curtipendula (sideoats grama)	0.21 (0.21)	0 (0)	0 (0)	50	0.42 (0.42)	0 (0)	0 (0)	50
	Cottea pappophoroides (cotta grass)	0 (0)	0 (0)	0 (0)	0	3.34 (3.34)	0 (0)	0 (0)	50
	Digitaria californica (Arizona cottontop)	0 (0)	0 (0)	0 (0)	0	0.21 (0.21)	0 (0)	0 (0)	50
	Leptochloa dubia (green sprangletop)	1.46 (1.46)	0.21 (0.21)	0 (0)	50	0.21 (0.21)	0 (0)	0 (0)	50
	Setaria leucopila (streambed bristlegrass)	5.21 (4.79)	1.04 (1.04)	0 (0)	10	1.67 (1.25)	0.21 (0.21)	0 (0)	100
	Sporobolus cryptandrus (sand dropseed)	0 (0)	0 (0)	0 (0)	0	0.21 (0.21)	0 (0)	0 (0)	100
	Sporobolus wrightii (big sacaton)	1.25 (1.25)	0 (0)	0 (0)	50	1.04 (1.04)	0.42 (0.42)	0 (0)	100
Shrubs/ Subshrubs	*Lycium andersonii* (water jacket)	0.42 (0.42)	0 (0)	0 (0)	50	0 (0)	0 (0)	0 (0)	0
	Senegalia greggii (catclaw acacia)	0.42 (0.42)	3.13 (3.13)	1.88 (1.88)	50	2.29 (2.29)	5.84 (5.84)	3.34 (3.34)	50
	Vachellia constricta (whitethorn acacia)	0 (0)	0 (0)	0.21 (0.21)	50	0 (0)	0 (0)	0 (0)	0
	Ziziphus obtusifolia (lotebush)	0.21 (0.21)	1.25 (1.25)	0 (0)	50	0 (0)	0.63 (0.21)	0.84 (0.84)	100
	Rivina humilis (rougeplant)	0 (0)	0 (0)	0 (0)	0	0.42 (0.42)	0 (0)	0 (0)	50
Trees	*Prosopis velutina* (velvet mesquite)	3.55 (3.13)	10.42 (2.09)	11.46 (8.13)	100	4.59 (3.34)	10.63 (1.05)	10.84 (9.17)	100
Vines	*Phaseolus ritens* (Santa Rita mountain bean)	0 (0)	0 (0)	0 (0)	0	0.84 (0.84)	0.21 (0.21)	0 (0)	50
	Phaseolus sp.	0.21 (0.21)	0.21 (0.21)	0 (0)	50	0 (0)	0 (0)	0 (0)	0

muhly (*Muhlenbergia porteri*), big sacaton (*Sporobolus wrightii*), and purple threeawn (*Aristida purpurea*) occurred in the understory.

Since no reference conditions were developed for this measure, the condition is unknown. Confidence is low because of the unknown condition. Data for this measure will be used to monitor plant populations and species of interest over time.

The following three paragraphs summarize the frequency of uncommon species for the native perennial plant community composition and structure indicator. Each paragraph summarizes a different unit of the NHP.

An additional 28 species or genera were observed in subplots in the Tumacácori Unit, including seven non-native species (Table 30). Each non-native species occurred during one round or the other but not both

Table 29. Percent cover and extent for perennial species in the Calabazas Unit in Tumacácori NHP.

Plant Group	Species	Round 1				Round 2			
		Field %Mean (SE)	Subcanopy % Mean (SE)	Canopy % Mean (SE)	Extent (%)	Field % Mean (SE)	Subcanopy % Mean (SE)	Canopy % Mean (SE)	Extent (%)
Forbs/Herbs	*Acourtia* sp. (desertpeony)	0.14 (0.14)	0 (0)	0 (0)	33.33	0 (0)	0 (0)	0 (0)	0
	Allionia incarnata (trailing windmills)	0.42 (0.42)	0 (0)	0 (0)	66.66	0 (0)	0 (0)	0 (0)	0
	Ambrosia confertiflora (weakleaf bur ragweed)	0 (0)	0 (0)	0 (0)	0	0.14 (0.14)	0 (0)	0 (0)	66.66
	Phemeranthus aurantiacus (orange fameflower)	0 (0)	0 (0)	0 (0)	0	0.69 (0.37)	0 (0)	0 (0)	100
	Portulaca suffrutescens (shrubby purslane)	0.14 (0.14)	0 (0)	0 (0)	66.66	0 (0)	0 (0)	0 (0)	0
	Senna bauhinioides (twinleaf senna)	0 (0)	0 (0)	0 (0)	0	0.14 (0.14)	0 (0)	0 (0)	66.66
	Talinum paniculatum (jewels of Opar)	0 (0)	0 (0)	0 (0)	0	4.17 (3.15)	0.28 (0.28)	0 (0)	100
Graminoids	*Aristida purpurea* (purple threeawn)	0.97 (0.97)	0 (0)	0 (0)	66.66	0.14 (0.14)	0 (0)	0 (0)	66.66
	Aristida ternipes (spidergrass)	0.14 (0.14)	0 (0)	0 (0)	33.33	0.70 (0.50)	0 (0)	0 (0)	100
	Bouteloua curtipendula (sideoats grama)	1.11 (0.91)	0 (0)	0 (0)	100	0.70 (0.50)	0 (0)	0 (0)	100
	Muhlenbergia porteri (bush muhly)	3.06 (2.85)	0 (0)	0 (0)	100	2.08 (1.50)	0 (0)	0 (0)	100
	Setaria leucopila (streambed bristlegrass)	0 (0)	0 (0)	0 (0)	0	0.14 (0.14)	0 (0)	0 (0)	100
	Sporobolus cryptandrus (sand dropseed)	0.42 (0.24)	0 (0)	0 (0)	100	0 (0)	0 (0)	0 (0)	0
	Sporobolus wrightii (big sacaton)	1.81 (1.81)	0 (0)	0 (0)	100	2.78 (2.18)	1.25 (1.25)	0 (0)	66.66
Succulents	*Cylindropuntia leptocaulis* (Christmas cactus)	0.14 (0.14)	0 (0)	0 (0)	66.66	0 (0)	0 (0)	0 (0)	0
Shrubs/ Subshrubs	*Acacia angustissima* (prairie acacia)	0 (0)	0.14 (0.14)	0 (0)	33.33	0 (0)	0 (0)	0 (0)	0
	Lycium berlandieri (Berlandier's wolfberry)	0 (0)	0 (0)	0 (0)	0	0.28 (0.28)	0.14 (0.14)	0 (0)	33.33
	Mimosa aculeaticarpa (catclaw mimosa)	0.28 (0.28)	0.42 (0.42)	0 (0)	33.33	0.14 (0.14)	0.42 (0.42)	0 (0)	66.66
	Senegalia greggii (catclaw acacia)	1.11 (0.37)	4.16 (0.83)	0.97 (0.97)	100	0.69 (0.69)	1.94 (1.55)	0.28 (0.28)	100
	Vachellia constricta (whitethorn acacia)	3.06 (2.85)	5.28 (4.47)	0 (0)	66.66	5.00 (4.79)	4.44 (3.84)	0 (0)	66.66
	Ziziphus obtusifolia (lotebush)	0 (0)	0.14 (0.14)	0 (0)	33.33	0 (0)	0 (0)	0 (0)	0
Trees	*Prosopis velutina* (velvet mesquite)	2.22 (0.50)	15.83 (2.29)	4.86 (2.43)	100	2.22 (0.50)	17.78 (3.68)	5.42 (3.13)	100

Table 30. Within-plot frequency for uncommon species in the Tumacácori Unit in Tumacácori NHP.

Plant Group	Species	Round 1 % Mean (SE)	Round 2 % Mean (SE)
Forbs/Herbs	*Argemone pleiacantha* (southwestern pricklypoppy)	0 (0)	2.9 (2.9)
	Cirsium neomexicanum (New Mexico thistle)	5.7 (5.7)	0 (0)
	Commelina erecta (whitemouth dayflower)	0 (0)	8.6 (6.0)
	*Conium maculatum** (poison hemlock)	5.7 (5.7)	0 (0)
	Datura wrightii (sacred thorn-apple)	0 (0)	2.9 (2.9)
	Rhynchosida physocalyx (buffpetal)	0 (0)	25.7 (10.4)
	Salsola sp.* (Russian thistle)	0 (0)	2.9 (2.9)
	*Sida abutifolia** (spreading fanpetals)	0 (0)	2.9 (2.9)
	*Sonchus asper** (spiny sowthistle)	5.7 (3.7)	0 (0)
	Stephanomeria pauciflora (brownplume wirelettuce)	0 (0)	2.9 (2.9)
Graminoids	*Aristida schiedeana* (single threeawn)	0 (0)	2.9 (2.9)
	Bouteloua repens (slender grama)	0 (0)	8.6 (8.6)
	*Bromus catharticus** (rescuegrass)	2.9 (2.9)	0 (0)
	Cottea pappophoroides (cotta grass)	8.6 (8.6)	0 (0)
	Hilaria belangeri (curly-mesquite)	5.7 (5.7)	0 (0)
	Setaria leucopila (streambed bristlegrass)	2.9 (2.9)	22.9 (11.1)
	*Sorghum halepense** (Johnsongrass)	0 (0)	2.9 (2.9)
	Sporobolus contractus (spike dropseed)	2.9 (2.9)	0 (0)
Shrubs/ Subshrubs	*Baccharis salicifolia* (mule-fat)	0 (0)	2.9 (2.9)
	Isocoma tenuisecta (burroweed)	17.1 (8.1)	8.6 (4.0)
	Lycium sp. (desert-thorn)	0 (0)	8.6 (6.0)
	Mimosa aculeaticarpa (catclaw mimosa)	2.9 (2.9)	5.7 (3.7)

* Non-native species.

Table 30 continued. Within-plot frequency for uncommon perennial species in the Tumacácori Unit in Tumacácori NHP.

Plant Group	Species	Round 1 % Mean (SE)	Round 2 % Mean (SE)
Shrubs/ Subshrubs *continued*	*Morus microphylla* (Texas mulberry)	0 (0)	8.6 (8.6)
	Tamarix ramosissima (saltcedar)	2.9 (2.9)	0 (0)
Succulents	*Cylindropuntia spinosior* (walkingstick cactus)	0 (0)	2.9 (2.9)
Trees	*Parkinsonia florida* (blue aloverde)	0 (0)	2.9 (2.9)
Vines	*Nissolia schottii* (Schott's yellowhood)	0 (0)	2.9 (2.9)
Unknown	*Prunus* sp. (plum)	2.9 (2.9)	0 (0)

* Non-native species.

rounds and exhibited <6% within-plot frequency. Three of the 28 species or genera exhibited within-plot frequencies of more than 10% during either round 1 or round 2.

In the Guevavi Unit, 17 additional species or genera were recorded in subplots that were not recorded on line transects, six of which exhibited more than 10% within-plot frequency during at least one sampling period (Table 31). Two of the 17 species reported were non-native with frequencies of 10% during at least one round of sampling.

In the Calabazas Unit, twenty-three species were recorded in sublplots that were not recorded on line transects, thirteen of which exhibited within-plot frequencies of more than 10% during at least one round (Table 32). Four non-native species were recorded in subplots, two of which exhibited frequencies of ≥20%.

No reference conditions were established for this measure. Therefore, the condition is unknown and confidence is low. The purpose of this measure is to track uncommon species over time, especially species that exhibit high annual variability in occurrence.

For the non-native plants indicator measure of extent, nineteen non-native plant species were encountered across all three park units (Table 33). Sixteen species occurred in the Tumacácori Unit, six species occurred in the Guevavi Unit, and seven species occurred in the Calabazas Unit. Four species occurred in all three units. The four species in all three units were bermudagrass

Table 31. Within-plot frequency for uncommon species in the Guevavi Unit in Tumacácori NHP.

Plant Group	Species	Round 1 % Mean (SE)	Round 2 % Mean (SE)
Forbs/Herbs	*Ambrosia confertiflora* (weakleaf bur ragweed)	0 (0)	20 (0)
	Ambrosia psilostachya (Cuman ragweed)	0 (0)	10 (10)
	*Descurainia sophia** (herb sophia)	10 (10)	0 (0)
	Rhynchosida physocalyx (buffpetal)	0 (0)	10 (10)
	*Sida abutifolia** (spreading fanpetals)	0 (0)	10 (10)
	Sida spinosa (prickly fanpetals)	0 (0)	30 (10)
	Talinum paniculatum (jewels of Opar)	0 (0)	10 (10)
	Tetramerium nervosum (hairy fournwort)	20 (20)	40 (40)
Graminoids	*Aristida ternipes* (spidergrass)	20 (20)	30 (10)
	Bothriochloa barbinodis (cane bluestem)	10 (10)	10 (10)
	Bouteloua chondrosioides (sprucetop grama)	0 (0)	10 (10)
	Bouteloua repens (slender grama)	0 (0)	20 (20)
	Muhlenbergia porteri (bush muhly)	10 (10)	10 (10)
Shrubs	*Celtis pallida* (spiny hackberry)	0 (0)	20 (20)
Trees	*Celtis laevigata* (sugarberry)	0 (0)	10 (10)
	Celtis reticulata (netleaf hackberry)	0 (0)	10 (10)
Vines	*Aristolochia watsonii* (Watson's dutchman's pipe)	0 (0)	10 (10)

* Non-native species.

(*Cynodon dactylon*), Lehmann lovegrass, ivyleaf morning-glory (*Ipomea hederacea*), and spreading fanpetals (*Sida abutifolia*). At least one non-native species occurred in every plot for 100% overall extent of non-native plants. Most species, however, exhibited less than 3% cover except for bermudagrass in the Tumacácori Unit where cover averaged 8.5% during round 1 and 7.1% during round 2. Species listed in Table 32 without cover values occurred only

Table 32. Within-plot frequency for uncommon species in the Calabazas Unit in Tumacácori NHP.

Plant Group	Species	Round 1 % Mean (SE)	Round 2 % Mean (SE)
Forbs/Herbs	*Abutilon parvulum* (dwarf Indian mallow)	0 (0)	6.7 (6.7)
	Acourtia nana (dwarf desertpeony)	13.3 (13.3)	13.3 (13.3)
	Commelina erecta (whitemouth dayflower)	0 (0)	33.3 (17.6)
	Commicarpus scandens (climbing wartclub)	0 (0)	26.7 (17.6)
	Heliomeris multiflora (showy goldeneye)	0 (0)	6.7 (6.7)
	*Portulaca oleracea** (little hogweed)	0 (0)	20.0 (20.0)
	Rhynchosida physocalyx (buffpetal)	0 (0)	13.3 (13.3)
	*Sida abutifolia** (spreading fanpetals)	0 (0)	26.7 (13.3)
	Sida neomexicana (New Mexico fanpetals)	0 (0)	13.3 (13.3)
	Solanum elaeagnifolium (silverleaf nightshade)	0 (0)	13.3 (13.3)
	Tetraclea coulteri (Coulter's wrinklefruit)	0 (0)	6.7 (6.7)
Graminoids	*Bouteloua radicosa* (purple grama)	0 (0)	6.7 (6.7)
	*Cynodon dactylon** (Bermudagrass)	0 (0)	6.7 (6.7)
	Hopia obtusa (vine mesquite)	0 (0)	20.0 (11.6)
	*Paspalum dilatatum** (dallisgrass)	0 (0)	6.7 (6.7)
Shrubs/ Subshrubs	*Croton pottsii* (leatherweed)	0 (0)	20.0 (20.20)
	Lycium sp. (desert-thorn)	6.7 (6.7)	0 (0)
	Polygala barbeyana (blue milkwort)	0 (0)	13.3 (13.3)
	Zinnia acerosa (desert zinnia)	13.3 (13.3)	13.3 (13.3)
Succulents	*Cylindropuntia spinosior* (walkingstick cactus)	6.7 (6.7)	13.3 (6.7)
	Ferocactus wislizeni (candy barrelcactus)	13.3 (6.7)	6.7 (6.7)
	Opuntia phaeacantha (tulip pricklypear)	6.7 (6.7)	6.7 (6.7)
Vines	*Passiflora mexicana* (Mexican passionflower)	0 (0)	6.7 (6.7)

* Non-native species.

Table 33. Extent and cover of non-native species in Tumacácori NHP.

Unit	Species	Round 1 % Extent (SE)	Round 1 % Mean Cover (SE)	Round 2 % Extent (SE)	Round 2 % Mean Cover (SE)
Tumacácori	*Bromus catharticus* (rescuegrass)	14.3 (14.3)	–	0 (0)	–
	Conium maculatum (poison hemlock)	14.3 (14.3)	–	0 (0)	–
	Cynodon dactylon (Bermudagrass)	57.1 (20.2)	8.5 (5.4)	71.4 (18.4)	7.1 (5.0)
	Eragrostis cilianensis (stinkgrass)	85.7(14.3)	1.4 (1.0)	28.6 (18.4)	0.1 (0.1)
	Eragrostis lehmanniana (Lehmann lovegrass)	42.9 (20.2)	0.1 (0.1)	42.9 (20.2)	0.5 (0.3)
	Ipomoea hederacea (ivyleaf morning-glory)	0 (0)	0 (0)	42.9 (20.2)	0.8 (0.6)
	Marrubium vulgare (horehound)	57.1 (20.2)	0 (0)	28.6 (18.4)	0.1 (0.1)
	Salsola (Russian thistle)	0 (0)		14.3 (14.3)	
	Salsola kali (Russian thistle)	71.4 (18.4)	2.4 (1.3)	42.9 (20.2)	0.1 (0.1)
	Salsola tragus (prickly Russian thistle)	0 (0)	0 (0)	28.6 (18.4)	0.6 (0.6)
	Sambucus nigra (black elderberry)	28.6 (18.4)	0 (0)	28.6 (18.4)	0 (0)
	Sida abutifolia (spreading fanpetals)	0 (0)	–	14.3 (14.3)	–
	Sisymbrium irio (London rocket)	42.9 (20.2)	0.1 (0.1)	0 (0)	0 (0)
	Sonchus asper (spiny sowthistle)	28.6 (18.4)	–	0 (0)	–
	Sorghum halepense (Johnsongrass)	0 (0)	–	14.3 (14.3)	–
	Tamarix ramosissima (saltcedar)	14.3 (14.3)	–	0 (0)	–
Guevavi	*Cynodon dactylon* (Bermudagrass)	0 (0)	0 (0)	100 (0)	0.8 (0.4)
	Descurainia sophia (herb sophia)	50 (50)	–	0 (0)	–
	Eragrostis cilianensis (stinkgrass)	100 (0)	1.5 (1.5)	100 (0)	0.2 (0.2)
	Eragrostis lehmanniana (Lehmann lovegrass)	50 (50)	2.1 (2.1)	50 (50)	2.7 (2.7)
	Ipomoea hederacea (ivyleaf morning-glory)	0 (0)	0 (0)	100 (0)	1.0 (0.2)
	Sida abutifolia (spreading fanpetals)	0 (0)	–	50 (50)	–
Calabazas	*Cynodon dactylon* (Bermudagrass)	0 (0)	–	33.3 (33.3)	–
	Eragrostis lehmanniana (Lehmann lovegrass)	0 (0)	0 (0)	33.3 (33.3)	0.8 (0.8)
	Ipomoea hederacea (ivyleaf morning-glory)	0 (0)	0 (0)	100 (0)	0.6 (0.4)
	Paspalum dilatatum (dallisgrass)	0 (0)	–	33.3 (33.3)	–
	Portulaca oleracea (little hogweed)	0 (0)	–	33.3 (33.3)	–
	Salsola kali (Russian thistle)	33.3 (33.3)	0.3 (0.3)	66.7 (33.3)	0.6 (0.3)
	Sida abutifolia (spreading fanpetals)	0 (0)	–	66.7 (33.3)	–

Note: Species without cover values occurred in subplots where cover was not recorded. *Sambucus nigra* appears to have been recorded along line transects, but with no cover values.

in subplots where cover was not measured. Since overall extent for each unit was 100%, the condition warrants moderate/significant concern. Confidence in the condition rating is high.

Total non-native plant cover was well below the 10% MAP in the Guevavi and Calabazas Units, but in the Tumacácori Unit, total non-native plant cover averaged between 9.2% and 12.4% (Table 34). These results warrant moderate/significant concern in the Tumacácori Unit. In the Guevavi and Calabazas Units, non-native plant cover levels indicate good condition. Confidence in the condition rating is high.

The proportion of total plant cover represented by non-native plants was well below the 25% MAP in the Guevavi and Calabazas Unit, which indicates good condition (Table 34). While the proportion of

Table 34. Non-native plant cover in Tumacácori NHP.

Unit	Measures	Round 1 % Mean (SE)	Round 2 % Mean (SE)
Tumacácori	Total Non-native Plant Cover (field)	12.4 (6.2)	9.2 (5.2)
	Ratio of Non-native Cover to Total Cover (field)	23.9 (9.4)	13.4 (6.4)
Guevavi	Total Non-native Plant Cover (field)	3.6 (3.6)	4.8 (3.1)
	Ratio of Non-native Cover to Total Cover (field)	6.1 (6.1)	8.2 (2.9)
Calabazas	Total Non-native Plant Cover (field)	0.3 (0.3)	1.9 (0.7)
	Ratio of Non-native Cover to Total Cover (field)	0.7 (0.7)	2.7 (1.2)

total plant cover represented by non-native plants approached the MAP in the Tumacácori Unit during round 1 (23.9%), this value was substantially lower during round 2 (9.2%). These results indicate good conditions for all units. Confidence in the condition rating is high.

Overall Condition, Threats, and Data Gaps

We used six indicators and 12 measures (summarized in Table 35) to assess the condition of upland vegetation and soils at Tumacácori NHP. Of the 12 measures, nine were assigned a condition rating based on SODN's MAPs. Three measures warranted significant/moderate concern (the two measures of fire hazard and the extent of non-native plants), while six measures were assigned good condition. Total non-native plant cover was in good condition for the Calabazas and Guevavi Units but warranted moderate/significant concern for the Tumacácori Unit. Measures with high confidence were given more weight in the overall condition rating than measures with medium or low confidence, and measures without a condition rating were not used to assess overall condition. In this assessment, all measures with a condition rating were assigned high confidence. There were some concerns regarding erosion hazard, fire hazard, and non-native plants. Therefore, the overall condition for upland vegetation and soils at Tumacácori NHP warrants moderate concern. Confidence in the overall condition rating is high, but because only two sampling periods have occurred to date, trends could not be determined. Vegetation, particularly grasses and forbs, vary widely depending on the amount of rainfall. Differences between rounds of sampling could have been due to water availability.

Small parks, such as Tumacácori NHP, are especially vulnerable to factors beyond their borders. Because of the historical park's small size and high amount of edge along the boundaries of the three separate units, edge effects such as non-native species encroachment is a persistent threat. Bermudagrass in particular has become well established at the historical park, and although total non-native plant cover was relatively low, cover for this species exceeded 7% in the Tumacácori Unit.

Non-native plant occurrence was substantially higher in the Tumacácori Unit than in either the Guevavi or Calabazas units, primarily because disturbance from flooding, trespass cattle, and active trails in the main unit is greater. The Calabazas and Guevavi units are closed to public access except during guided NPS tours at specific dates and times (Powell et al. 2005). Furthermore, neither of these units were developed for agriculture as parts of the Tumacácori Unit were (Studd and Zepp 2009). The Santa Cruz River, which flows through the historical park during part of the year, may also carry non-native species into the park (Powell et al. 2005). Lastly, all of the park's infrastructure is located in the Tumacácori Unit, including park headquarters, office buildings, and employee housing (Powell et al. 2005). These disturbed areas contribute to non-native plant dispersal and establishment.

A complete park inventory conducted from 2000 to 2003 found 67 non-native plant species across the park's three units (Powell et al. 2005). In a 2006 survey of non-native plants in the park, including all habitat types, the authors found 14 of 75 targeted non-native species across the three park units (Studd and Zepp 2009), while 19 species were reported in uplands alone during current surveys (this assessment). These numbers suggest that many of the non-native species have not become well established in the NHP. However, once a non-native species becomes established, they are often extremely difficult to control and most will never be completely eradicated (Mack et al. 2000).

Table 35. Summary of upland vegetation and soils indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Erosion Hazard	Bare Ground Cover		Measurements across all three units and in both survey periods averaged less than the 20% MAP, which indicates good condition for this measure. Bare ground cover did not exceed 10%. Confidence in the condition rating is high. With only two rounds of sampling, trend could not be determined.
	Soil Aggregate Stability		Soil aggregate stability slightly exceeded class 3 in both the Tumacácori and Guevavi units during both rounds of surveys, which indicates moderately stable soils and meets the MAP. However, in the Calabazas Unit, soil stability averaged 1.67 during round two. Overall, these data indicate good conditions across the NHP, but there may be some concerns regarding soil stability in the Calabazas Unit. Trend could not be determined based on two sample periods. Confidence in the condition rating is high.
Erosion Features	Extent of Area by Erosion Feature Type		Erosion features by area across the three units was low (~2.5%), and there was no change in the estimated degraded area for plots that were surveyed twice. Furthermore, there was no evidence of tunneling, pedestals, or terracettes in any of the plots during either time period, but burrowing was recorded in most plots during both time periods (these features are precursors to erosion). No reference conditions were established for this measure so the condition is unknown. Trend could not be determined. Confidence in the condition rating is low because of the unknown condition.
Site Resilience	Foliar Cover of Dead Perennial Plants (field)		Foliar cover of dead perennial plants in the field layer was substantially lower during round 2 than during round 1 in all three units. During round 1 values approached the MAP of 15% in the Tumacácori and Calabazas Units and exceeded the MAP in the Guevavi Unit. However, only this measurement exceeded the MAP. Furthermore, given the substantial difference and decline in foliar cover of dead plants from round 1 to round 2, the condition for this measure is good. Confidence in the condition rating is high. Trend could not be determined.
	Foliar Cover of Dead Perennial Plants (subcanopy)		Foliar cover of dead perennial plants in the subcanopy did not exceed 3% in either time period or park unit. Since all measurements were well below the 15% MAP, the condition for this measure is good. Trend could not be determined. Confidence in the condition rating is high.
Fire Hazard	Grass and Forb Cover (field)		Grass and forb cover exceeded the 30% MAP for both sampling periods and park units except in round 1 of the Calabazas Unit; however, this value (~25%) approached the MAP and was substantially higher during round 2 (~70%). Since percent cover was greater than 30% for the most measurements, this measure of fire hazard warrants moderate/significant concern. Confidence in the condition rating is high. Trend could not be determined.
	Ratio of Annual Plant Cover to Total Plant Cover		The proportion of total cover represented by annuals was double or nearly double the 25% MAP for both time periods and all three park units. Given the large margins of error relative to the values however, differences between time periods may not be significant. The condition for this measure of fire hazard warrants moderate/significant concern. Trend is unknown. Confidence in the condition rating is high.
Native Perennial Plant Community Composition and Structure	Cover of Common Species		Along line transects, thirty-three species were observed in the Tumacácori Unit, 18 in the Guevavi Unit, and 22 in the Calabazas Unit. All lifeforms were represented across the three units. In general, cover was low regardless of vegetation layer or lifeform. Since no reference conditions were developed for this measure, the condition is unknown. Confidence is low because of the unknown condition. Trend could not be determined.

Table 35 continued. ***Summary of upland vegetation and soils indicators, measures, and condition rationale.***

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Native Perennial Plant Community Composition and Structure *continued*	Frequency of Uncommon Species		In the Tumacácori Unit, twenty-eight species were observed in subplots that were not observed along line transects, three of which exhibited frequencies greater than 10%. In the Guevavi Unit, there were 17 species, six of which had greater than 10% frequency. In the Calabazas Unit, 13 of the 23 species exhibited frequencies greater than 10%. Since no reference conditions were developed for this measure, the condition is unknown. Confidence is low because of the unknown condition. Trend could not be determined.
Non-native Plants	Extent		Nineteen non-native plant species were encountered across all three park units. Sixteen species occurred in the Tumacácori Unit, six in the Guevavi Unit, and seven in the Calabazas Unit. Four species occurred in all three units. These species were bermudagrass, Lehmann lovegrass, ivyleaf morning-glory, and spreading fanpetals. At least one non-native species occurred in every plot for 100% overall extent of non-native plants, which warrants moderate/significant concern. Confidence in the condition rating is high. Trend is unknown.
	Total Cover	Tumacácori	In the Tumacácori Unit, total non-native plant cover was between 9.2% and 12.4%. These results warrant moderate/significant concern. Confidence in the condition rating is high. Trend is unknown.
	Total Cover	Guevavi/ Calabazas	Total non-native plant cover was well below the 10% MAP in the Guevavi and Calabazas Units during both rounds of sampling, which indicates good condition. Confidence in the condition rating is high. Trend is unknown.
	Ratio of Non-native Plants to Total Plant Cover (field)		The proportion of total plant cover represented by non-native plants was well below the 25% MAP in the Guevavi and Calabazas Units, which indicates good condition. While the proportion of total plant cover represented by non-native plants approached the MAP in the Tumacácori Unit during round 1 (23.9%), this value was substantially lower during round 2 (9.2%). These results indicate good conditions for all units. Confidence in the condition rating is high. Trend could not be determined.
Overall Condition	Summary of All Measures		Five of nine measures were assigned a condition rating of good, while three measures warrant moderate/significant concern. The condition of total non-native plant cover varied by unit. There were 19 non-native species recorded in plots across the historical park, and several of them are widespread. Non-native plants can and do cause significant disruption to ecosystem structure and function. For these reasons the overall condition warrants moderate concern. Confidence is high. Trend is unknown.

Staff at Tumacacori NHP have and continue to treat and control non-native plants, particularly tamarisk in the riparian zone (NPS, S. Studd, vegetation ecologist, comments to draft assessment, 24 May 2018).

The western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall during the last 50 years (Prein et al. 2016). Since 1974 there has been a 25% decrease in precipitation, a trend that is partially counteracted by increasing precipitation intensity (Prein et al. 2016). In an analysis of climate variables in the NHP, Monahan and Fisichelli (2014) found that recent climate conditions indicate a shift from the natural range of variability toward warmer temperatures. While no precipitation variables were classified as extreme dry (i.e., exceeding 95% of the historical range of conditions), warmer temperatures could reduce the amount of soil moisture available for plants in addition to increasing rates of evapotranspiration.

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Subject matter expert reviewers for this assessment are listed in Appendix A.

Riparian Vegetation

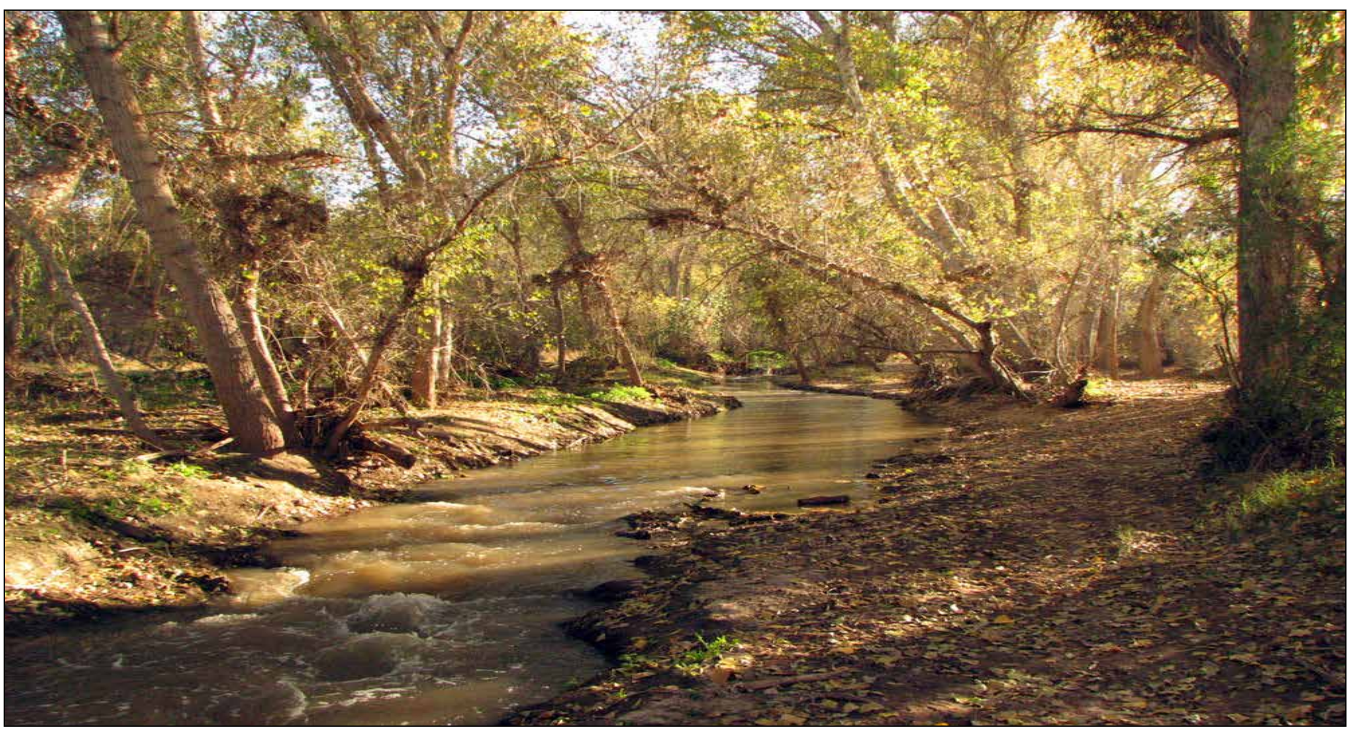
Background and Importance

Riparian habitat in the southwestern U.S. is a rare but critically important resource for birds, invertebrates, mammals, fish, and other wildlife (Poff et al. 2011). Many species depend on riparian vegetation, particularly woody plants, for breeding, foraging, as migration habitat, and for regulating stream temperature. Additional beneficial riparian attributes include erosion control, nutrient cycling, flood mitigation, increased groundwater recharge, and improved water quality, in part by buffering pollutants, making riparian areas highly productive ecosystems if functioning properly. Over the last 100 years, however, woody riparian habitat in the arid southwestern U.S. has declined as a result of agriculture, resource extraction, and development (Stromberg 2001).

The National Park Service's (NPS) Sonoran Desert Inventory and Monitoring Network (SODN) surveys riparian vegetation along the Santa Cruz River in Tumacácori National Historical Park (NHP) to better understand current condition and patterns of change over time (Gwilliam et al. 2014a). Monitoring riparian vegetation is one aspect of SODN's comprehensive streams monitoring program, which also includes hydrology, stream channel morphology, water quality, and aquatic wildlife surveys. These topics are addressed in separate assessments in this report.

An approximately 2.3 km (1.4 mi) stretch of the Santa Cruz River flows through the Tumacácori unit, which was acquired by the NPS in 2002 (Buckley 2010). The Santa Cruz River flows from its headwaters in Arizona's San Rafael Valley south into Mexico and then north back into the U.S. at Nogales, Arizona (Brewer and Fabrtiz-Whitney 2012). Historically, the Santa Cruz River flowed perennially from its headwaters to Tubac, Arizona just north of Tumacácori NHP (Wood et al. 1999). Today, streamflow in this 72-km (45-mi) stretch of river is dependent on stormwater from high flow events and on effluent discharged from the Nogales International Wastewater Treatment Plant, which treats water from both the U.S. and Mexico (Brewer and Fabritz-Whitney 2012).

Changes in stream flow have altered riparian vegetation along the river, but the most dramatic changes to the Santa Cruz River valley occurred after the arrival of the Spanish in the late 1600s (Buckley 2010). The Spanish grazed thousands of sheep and cattle in the region and utilized surface water from the Santa Cruz River. From the 1800s through the early 1900s, ranchers continued to clear riparian vegetation and girdle cottonwoods (*Populus* spp.) in the mistaken belief that woody riparian plants competed with them for limited water resources (Buckley 2010). Despite these changes, Freemont cottonwood (*Populus fremontii*) and Goodding's willow (*Salix gooddingii*) forests have



Cottonwood gallery forest along the Santa Cruz River in Tumacácori NHP. Photo Credit: NPS.

persisted along the Santa Cruz River, but non-native and upland species have encroached on this habitat type (Drake et al. 2009, Studd and Zepp 2009).

Data and Methods

This assessment is based on two indicators (loss of obligate wetland plants and non-native plant dispersal and invasion) with a total of three measures. Data were collected as part of the SODN's riparian plant monitoring program at Tumacácori NHP (Gwilliam et al. 2018).

Vegetation was surveyed during August 2013 and 2018 in each of two zones extending perpendicular to the river corridor. The two zones were the greenline and the riparian zone. The greenline zone includes "vegetation found in the first line of perennial vegetation from the stream wetted edge, usually within 10 m (33 ft)" (Gwilliam et al. 2018). The riparian zone "extends from the active river channel out to an indeterminate point where the transition to uplands is complete" (Gwilliam et al. 2018). SODN also monitors aquatic (submerged) vegetation; however, those data were unavailable for inclusion in this report.

Stream vegetation was surveyed in each zone using the point-intercept method. Transects were 20-m (65.6-ft) long perpendicular to stream channel cross-sections (i.e., transects were parallel to the stream channel). A total of 58 transects were surveyed in Tumacácori NHP in 2013 (38 in the riparian zone and 20 in the greenline). In 2018, 20 transects were monitored in the both the greenline and the riparian zone. Vegetation cover was measured using a fiberglass rod approximately 1.5 m × 8 mm (4.9 ft x 0.3 in) in diameter. Sampling occurred at 1.0 m (3.2 ft) intervals along the transect, starting at 1.0 m (3.2 ft) for a total of 20 sampling points. Vascular plants in contact with the rod were identified in each of three structural layers. The layers were as follows: herbaceous (1 cm–0.5 m [0.4 in–1.6 ft]), subcanopy (0.5–2 m [1.6–6.6 ft]) and canopy (>2 m [>6.6 ft]). Due to changes in SODN's database structure, only 2018 plant frequency data were entered and available for this assessment. The remaining measures were based on 2013 data only.

Loss of obligate wetland plants was evaluated using the measure richness and distribution. Richness is the number of species occurring in a given area. The purpose of this measure is to determine the number of obligate wetland plants in each vegetation zone.

Park trail winds through riparian vegetation in Tumacácori NHP. Photo Credit: NPS.

Obligate wetland plants depend on near surface groundwater for growth, reproduction, and survival. Their presence can be a good indicator of stream health. In contrast, the loss of obligate wetland plants can illuminate issues on declining water tables and/or reduced streamflow. Changes in the lateral distribution of obligate wetland plants across stream vegetation zones helps scientists determine changes in stream vegetation width and the amount of habitat available for obligate wetland species.

For each plant species, we determined its wetland status using the U.S. Department of Agriculture's (USDA) PLANTS Database (USDA 2018). Plants were divided into five categories based on wetland status. The categories are: obligate wetland (OBL = almost always occurs in wetlands), facultative wetlands (FACW = usually occurs in wetlands but may occur in non-wetlands), facultative (FAC = occurs in wetlands and non-wetlands), facultative upland (FACU = usually occurs in non-wetlands), and obligate upland (UPL = almost never occurs in wetlands).

Non-native plant dispersal and invasion was evaluated using the measures frequency and cover. Frequency indicates the extent to which non-native species have invaded stream zones. Scientists can determine if non-native species are widespread throughout the stream channel or if species are concentrated within a particular zone. These data will help managers better address non-native species in the park. Frequency data were collected within a 2.0-m (6.6-ft) wide frequency plot, centered around the transect (1.0 m [3.2 ft] on either side except along greenline transects where the 2.0 m [6.6 ft] plots were all inland from the stream). Frequency is the presence of any non-native annual species that is rooted within the frequency plot but that was not already recorded during the point-intercept sampling.

Percent cover of non-native species complements the frequency measure. Cover informs how much ground surface area a particular species or group of species represents. A particular species may be widespread as indicated by high frequency but exhibit low cover. Or a species may exhibit low frequency but high cover, or even both high frequency and cover. Along with frequency, cover data can help managers prioritize which non-native species are in most need of control. Percent cover was calculated by summing the number of point-intercept "hits" for a particular taxon by structural layer and then dividing the number of hits by the number of total possible hits. The total possible "hits" was 20 since cover is measured at 1 m (3.2 ft) intervals along the transect. Percent cover was calculated by vegetation zone.

Reference Conditions

Reference conditions are described for resources in good and moderate/significant concern conditions for each of the three measures (Table 36). Reference conditions were based on Management Assessment Points (MAPS) developed by SODN for Montezuma Castle National Monument (NM) and Tuzigoot NM (Gwilliam et al. 2014b). We used the same MAPS because all three units are located within the Apache Highlands Ecoregion and support similar riparian vegetation (Gwilliam et al. 2014a,b). MAPS "represent preselected points along a continuum of resource-indicator values where scientists and managers have together agreed that they want to stop and assess the status or trend of a resource relative to program goals, natural variation, or potential concerns" (Bennetts et al. 2007). MAPS do not define management goals or thresholds. Rather, MAPS "serve as a potential early warning system," where managers may consider possible actions and options (Bennetts et al. 2007). We used MAPs developed for Montezuma Castle and Tuzigoot NM because no MAPs have been developed specifically for Tumacácori NHP. The only change we made used transects rather than plots for the percent frequency reference conditions. The 95% confidence intervals for richness were calculated based on mean richness for obligate wetland taxa across the plots within each zone.

Condition and Trend

A total of 28 native species occurred across the greenline and riparian zones, nine of which were found in the greenline and 23 of which were found in the riparian zone (Table 37). Four species occurred in both zones. Species richness averaged 1.75 in the greenline and 2.55 in the riparian zone. The greater species richness in the riparian zone may be at least partially attributed to differences in sample size (i.e., 20 greenline transects vs. 38 riparian transects).

Seep monkeyflower (*Mimulus guttatis*) and dotted smartweed (*Persicaria punctata*) were the only OBL species found in the greenline. The greenline also included two FACW species, one FAC species, two FACU species, and one UPL species. Fremont cottonwood was not assigned a wetland indicator status, but this species is characteristically associated with riparian areas and can serve as an indicator of shallow groundwater tables (Stromberg 2013). No OBL species were documented in the riparian zone. In order of most dependent on wetlands were FACW (1), FAC (6), FACU (6), and UPL (2). The remaining eight species, including Fremont cottonwood, were not assigned a wetland indicator status.

Typical wetland species such as rushes (*Juncus* spp.) and horsetails (*Equisetum* spp.) were not encountered during SODN's 2013 surveys but were encountered

Table 36. Reference conditions used to assess riparian vegetation in Tumacácori NHP.

Indicators	Measures	Good	Moderate Concern/Significant Concern
Loss of Obligate Wetland Plants	Richness and Distribution	Within baseline 95% confidence interval for wetland obligate taxa richness and distribution.	Outside baseline 95% confidence interval for wetland obligate taxa richness and distribution.
Non-native Plant Dispersal and Invasion	Percent Frequency	≤ 50% of transects	> 50% of transects
	Percent Cover	% total plant cover is ≤ 10% non-native in each structural layer.	% total plant cover is >10% non-native in each structural layer.

Source: Gwilliam et al. (2014a).

Table 37. Native species in the greenline and riparian zone.

Vegetation Zone	Species	Common Name	Wetland Status*
Greenline	*Baccharis salicifolia*	Mule-fat	FAC
	Chloris virgata	Feather fingergrass	FACU
	Hymenoclea monogyra	Singlewhorl burrobrush	UPL
	Mimulus guttatus	Seep monkeyflower	OBL
	Morus microphylla	Texas mulberry	FACU
	Paspalum distichum	Knotgrass	FACW
	Persicaria punctata	Dotted smartweed	OBL
	Populus fremontii	Fremont cottonwood	-
	Salix gooddingii	Gooding's willow	FACW
Riparian	*Ambrosia psilostachya*	Cuman ragweed	FACU
	Aristida ternipes	Spidergrass	–
	Baccharis salicifolia	Mule-fat	FAC
	Baccharis sarothroides	Desertbroom	FACU
	Boerhavia coccinea	Scarlet spiderling	–
	Bouteloua curtipendula	Sideoats grama	–
	Celtis ehrenbergiana	Spiny hackberry	–
	Celtis reticulata	Netleaf hackberry	FAC
	Cenchrus spinifex	Coastal sandbur	–
	Clematis ligusticifolia	Western white clematis	FAC
	Commelina erecta	Whitemouth dayflower	FACU
	Datura wrightii	Sacred thorn-apple	UPL
	Fraxinus velutina	Velvet ash	FAC
	Funastrum cynanchoides var. *hartwegii*	Hartweg's twinevine	FACU
	Hymenoclea monogyra	Singlewhorl burrobrush	UPL
	Juglans major	Arizona walnut	FAC
	Mirabilis longiflora	Sweet four o'clock	–
	Parkinsonia aculeata	Jerusalem thorn	FAC
	Populus fremontii	Fremont cottonwood	–
	Prosopis velutina	Velvet mesquite	FACU
	Salix gooddingii	Goodding's willow	FACW
	Sporobolus cryptandrus	Sand dropseed	FACU
	Ziziphus obtusifolia	Lotebush	–

* OBL = almost always occurs in wetlands, FACW = usually occurs in wetlands but may occur in non-wetlands, FAC = occurs in wetlands and non-wetlands, FACU = usually occurs in non-wetlands, and UPL = almost never occurs in wetlands.

in small patches during the 2007-2008 vegetation mapping effort in the NHP (Drake et al. 2009). Smooth horsetail (*Equisetum lavigatum)* was also documented along the Santa Cruz River during the 2000-2003 vascular plant inventory (Powell et al. 2005). Big sacaton (*Sporobolus wrightii*), a FAC species, is thought to have been historically common in flooded riparian areas along the Santa Cruz River, but this species was not encountered during SODN's 2013 sampling. Big sacaton was however, encountered in small patches during 2007-2008 mapping effort (Drake et al. 2009) and during the 2000-2003 inventory by Mouat et al. (1977) as cited in Powell et al. (2005).

Webb et al. (2007) and Powell et al. (2005) as cited in Drake et al. (2009) state that there has been an increase in obligate riparian vegetation within the NHP after the 1930s as a result of agricultural abandonment, but this increase appears to be extremely limited to a few species. Drake et al. (2009) note that the rarity of OBL species indicates an impoverished riparian ecosystem, but also points toward an opportunity for restoration of these herbaceous species because they have persisted in small patches. The apparent absence of all but two OBL species during the 2013 sampling does not necessarily indicate that they were not present. Rare species are often difficult to sample and may have been absent along the transects but persisting in areas not sampled.

Although the loss of riparian obligate species is well documented (Powell et al. 2005, Drake et al. 2009), SODN has conducted only one survey to date, so we could not determine condition based on reference conditions. Therefore, the condition of richness and distribution is unknown. Confidence in the condition rating is low because of the unknown condition. Trend will be based on future sampling efforts conducted by SODN.

For the frequency measure of the non-native plant dispersal and invasion indicator, there were twenty-four non-native species encountered across the two zones. Over the two years, 14 non-native species were observed in the riparian zone and at least one non-native species was observed along 17 of the 38 transects for an overall frequency of 45% in 2013 (Table 38). In 2018 at least one non-native species occurred in 12 of the 20 frequency plots for 60% non-native plant frequency. Frequency for individual species in the riparian zone ranged from 5% to 15%. Poison hemlock (*Conium maculatum*), bermudagrass (*Cynodon dactylon*), prickly Russian thistle (*Salsola tragus*) were the most frequently encountered species. Although frequency was similar by species between years, the sample size was reduced by about half in 2018 so values may not be directly comparable. While the overall frequency in 2013 indicates good condition, this value is approaching the management assessment point of 50%. In 2018, frequency exceeded the management assessment point. Therefore, the condition for non-native plants in the riparian zone is of moderate/significant concern. Confidence in the condition rating is high. Trend could not be determined.

In the greenline, 20 non-native species were observed over the two years (Table 39). At least one non-native species was encountered in 18 of 20 transects in 2013 and all 20 transects in 2018 for 90% and 100% frequency, respectively. Frequency by species ranged from 5% to 65%. Although overall frequency was similar between the two years, species frequency increased substantially for some species. These species include poison hemlock, watercress (*Nasturtium officinale*), and curly dock (*Rumex crispus*). Furthermore, several species that were not encountered in 2013 were found in high frequency in 2018. These species include tree tobacco (*Nicotiana glauca*), spotted ladysthumb (*Polygonum persicaria*), and annual rabbitsfoot (*Polypogon monspeliensis*). Although the sample size was the same between years, with only two years of data, we could not determine if this increase represents a trend. However, given the high overall frequency in both years, the condition is of moderate/significant concern. Confidence is high.

Table 38. Non-native plant frequency in the riparian zone.

Species	Common Name	Frequency (%)	
		2013	2018
Conium maculatum	Poison hemlock	11	10
Cynodon dactylon	Bermudagrass	13	15
Echinochloa crus-galli	Barnyard grass	8	–
Eragrostis lehmanniana	Lehmann lovegrass	–	5
Lactuca serriola	Prickly lettuce	5	–
Melilotus sp.	Sweetclover	3	–
Nicotiana glauca	Tree tobacco	–	10
Portulaca oleracea	Little hogweed	5	–
Rumex crispus	Curly dock	3	–
Salsola sp.	Russian thistle	3	–
Salsola tragus	Prickly Russian lettuce	8	10
Sambucus nigra	Blue elderberry	5	5
Sonchus asper	Spiny sowthistle	5	5
Sorghum halepense	Johnsongrass	5	5

For the cover measure of the non-native plant dispersal and invasion indicator, non-native plants accounted for 53% of the 58% total cover in the herbaceous layer of the greenline (Table 40). In the subcanopy, 2% of the 18% total cover was comprised on non-native species, and in the canopy, only two species were present (cottonwood and willow), both of which are native species. Total cover averaged 57% and non-native cover was 0%.

Table 39. Non-native plant frequency in the greenline.

Species	Common Name	Frequency (%)	
		2013	2018
Bromus catharticus	Rescuegrass	–	5
Conium maculatum	Poison hemlock	20	55
Dysphania ambrosioides	Mexican tea	–	25
Echinochloa crus-galli	Barnyard grass	45	5
Ipomoea hederacea	Ivy-leaf morning-glory	15	15
Lactuca serriola	Prickly lettuce	–	15
Melilotus sp.	–	5	35
Melilotus alba	Sweetclover	–	5
Melilotus officinalis	Sweetclover	–	10
Mirabilis jalapa	Marvel of Peru	5	–
Nasturtium officinale	Watercress	5	50
Nicotiana glauca	Tree tobacco	–	60
Persicaria maculosa	Spotted ladysthumb	–	5
Plantago major	Common plantain	–	20
Polygonum aviculare	Prostrate knotweed	10	30
Polygonum persicaria	Spotted ladysthumb	–	65
Polypogon monspeliensis	Annual rabbitsfoot grass	–	60
Rumex crispus	Curly dock	5	45
Salsola sp.	Russian thistle	–	5
Sambucus nigra	Blue elderberry	5	5
Sorghum halepense	Johnsongrass	20	60

In the riparian zone, total cover in the herbaceous layer was 32%, 21% of which was non-native plant cover. In the subcanopy, total cover averaged 16%, 1% of which was non-native. Lastly, total cover averaged 45% and non-native cover averaged 0.5% in the canopy layer.

Although non-native species cover declined with vegetation height in both zones, most non-native species tend to be forbs and grasses. Because of the high cover in the herbaceous layer, the condition warrants moderate/significant concern. Trend is unknown. Confidence in the condition rating is high.

Table 40. Percent total cover and cover of non-native species by vegetation zone and layer.

Vegetation Zone	Vegetation Layer	% Total Cover (SE)	% Non-native Cover (SE)
Greenline	Herbaceous	58 (5.3)	53 (5.2)
	Subcanopy	18 (4.7)	2 (0.7)
	Canopy	57 (7.1)	0 (0)
Riparian	Herbaceous	32 (4.0)	21 (3.8)
	Subcanopy	16 (2.6)	1 (0.3)
	Canopy	45 (6.4)	0.5 (0.5)

Overall Condition, Threats, and Data Gaps

We used two indicators and three measures (summarized in Table 41) to assess the condition of riparian vegetation along the Santa Cruz River in Tumacácori NHP. The two non-native plant measures warrant moderate/significant concern, but we could not assess the loss of riparian obligate plants based on one year of data. Nevertheless, the apparent lack of riparian obligate plants, prevalence of upland species, and occurrence of non-native plants yielded an overall condition rating of moderate/significant concern. Confidence in the overall condition rating is high. Trends could not be determined based on one or two years of data. Trends moving forward will be determined based on comparisons with future monitoring data. A key uncertainty is whether the transects captured all of the species (native and non-native) present in the riparian and greenline vegetation zones. Species-area curves can help determine this. Data from previous studies suggest that either there has been a loss of riparian obligate species between 2000 and 2010 or that current surveys did not capture those species because they are rare.

Since the 2.6 km (1.4 mi) Santa Cruz River corridor came under NPS protection in 2002, the threat of land development and alteration within this stretch was eliminated (NPS 2014a). However, by this time, riparian vegetation had been substantially altered. Aerial photographs of the area show that by the 1950s much of the riparian area had been cleared (Buckley 2010). It wasn't until the 1970s, however, that agricultural fields surrounding the park were abandoned and vegetation began to grow back as evident in aerial photos from the late 1990s and early 2000s (Buckley 2010).

Despite these alterations, cottonwood and willow remain, along with at least two riparian obligate

Table 41. Summary of riparian vegetation indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Loss of Obligate Wetland Plants	Richness and Distribution		Species richness was higher in the riparian zone than in the greenline, but the only two OBL species occurred in the greenline. Only two FACW species occurred in the greenline and only one FACW occurred in the riparian zone. Three species were associated with uplands in the greenline and eight species were associated with uplands in the riparian zone. Previous studies suggest a loss of OBL species over time, but because SODN has conducted only one survey to date, and the reference condition is based on change over time, the condition is unknown. Because of the unknown condition, confidence is low. Trend will be based on comparison with future surveys.
Non-native Plant Dispersal and Invasion	Percent Frequency		Non-native species were widespread in both vegetation zones. In the riparian zone, non-native species occurred in 45% and 60% of plots during 2013 and 2018, respectively. In the greenline, 90% and 100% of plots contained at least one non-native species in 2013 and 2018, respectively. Across both zones and years, there were 24 non-native species. Because overall frequency exceeded 50% in each zone, these results warrant moderate/significant concern. Trend could not be determined based on two rounds of sampling. Confidence in the condition rating is high.
	Percent Cover		Like frequency, percent cover of non-native species was high, particularly in the herbaceous layer. In the greenline, cover averaged 53%, while total cover was 58%. In the riparian zone, non-native plants represented 21% of 32% total cover. Cover for non-native species in the subcanopy averaged approximately 1% to 2%. Non-native plants averaged <1% in the canopy layer. Because non-native cover exceeded 10% in the herbaceous layer, the condition warrants moderate/significant concern. Trend could not be determined based on one round of sampling.
Overall Condition	Summary of All Measures		The loss of obligate wetland species had occurred decades before SODN began monitoring riparian vegetation. Only two OBL species were documented in the greenline and none were documented in the riparian zone. In addition, non-native plant frequency and cover was high in both zones. There may have been additional OBL species, but because they are rare, these species are difficult to monitor.

species. The presence of willows, cottonwoods, and other riparian species that persist along the Santa Cruz River in Tumacácori NHP provide an opportunity to restore native riparian vegetation, particularly with the return of streamflow from the Nogales International Wastewater Treatment Plant. However, continued flows are uncertain as Mexico retains full legal rights to the effluent discharged into the river (Brewer and Fabritz-Whitney 2012).

The primary threat to the persistence of existing riparian species and the establishment of lost riparian obligate species is streamflow. Current groundwater levels are good for the persistence of mature cottonwood and willows but not for the establishment of juveniles as described in the hydrology assessment in this report. While woody riparian plants have persisted in Tumacácori NHP, prolonged drought stress will eventually cause mortality. Even deep-rooted, well-established cottonwood trees are susceptible to annual changes in groundwater and streamflow. In 2013 for example, cottonwoods along the Santa Cruz River in Tumacácori NHP dropped their leaves in response an extended absence of flowing water (NPS 2013).

The duration and frequency of droughts are likely to increase as the climate continues to change. The western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall during the last 50 years (Prein et al. 2016). Since 1974 there has been a 25% decrease in precipitation, a trend that is partially counteracted by increasing precipitation intensity (Prein et al. 2016). In an analysis of climate variables in the park, Monahan and Fisichelli (2014) found that recent climate conditions indicate a shift from the natural range of variability toward warmer temperatures. While no precipitation variables were classified as extreme dry (i.e., exceeding 95% of the historical range of conditions), warmer temperatures could reduce the amount of soil moisture available for plants in addition to increasing rates of evapotranspiration.

Drier conditions and changes in hydrology and patterns of land use have allowed for upland and non-native species to encroach into the riparian area (Drake et al. 2009, Studd and Zepp 2009). Once non-native species become established, they are often extremely difficult to control and most will never be completely eradicated, particularly grasses such as Lehmann lovegrass (*Eragrostis lehmanniana*) (Mack et al. 2000).

In 2008 there was a widespread, moderate to high severity fire at the park that spread through the riparian area, killing many cottonwood trees. Cottonwood trees are continuing to die and fall more than a decade since the fire (NPS, S. Studd, ecologist, comments to draft assessment, 3 February 2019). There was also small restoration effort where cottonwood trees were planted and watered, but the results of this effort are unknown (NPS, S. Studd, ecologist, comments to draft assessment, 3 February 2019).

Other threats to native vegetation include illegal trespass from all terrain vehicles, livestock, horses, and off-trail use by humans (NPS 2014a). These factors not only destroy native vegetation through trampling and foraging of cattle and horses, but they also increase the dispersal of non-native plants, and de-stabilize the stream bank.

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University.

Birds

Background and Importance

Changes in bird population and community parameters have been identified as an important element of a comprehensive, long-term monitoring program at Tumacácori National Historical Park (NHP) (Beaupré et al. (2013). In the bird monitoring protocol for the Sonoran Desert Network (SODN) and other networks, Beaupré et al. (2013) describe how landbird monitoring contributes to a basic understanding of park resources and associated habitats as follows:

> Landbirds are a conspicuous component of many ecosystems and have high body temperatures, rapid metabolisms, and occupy high trophic levels. As such, changes in landbird populations may be indicators of changes in the biotic or abiotic components of the environment upon which they depend (Canterbury et al. 2000; Bryce et al. 2002). Relative to other vertebrates, landbirds are also highly detectable and can be efficiently surveyed with the use of numerous standardized methods (Bibby et al. 2000; Buckland et al. 2001).
>
> Perhaps the most compelling reason to monitor landbird communities in parks is that birds themselves are inherently valuable. The high aesthetic and spiritual values that humans place on native wildlife is acknowledged in the agency's Organic Act: "to conserve . . . the wild life therein. . . unimpaired for the enjoyment of future generations." Bird watching, in particular, is a popular, long-standing recreational pastime in the U.S., and forms the basis of a large and sustainable industry (Sekercioglu 2002).

Data and Methods

Tumacácori NHP is divided into three small separate units. The three units are the Tumacácori Unit, the Calabazas Unit, and the Guevavi Unit. In addition to riparian habitat, the Tumacácori Unit also contains mesic mesquite bosque habitat (Mau-Crimmins et al. 2005). The other two units support semi-desert grasslands (Mau-Crimmins et al. 2005). This assessment focuses on birds in the Tumacácori Unit because the majority of bird surveys have occurred there and because data for this unit are most current. However, all species found throughout the historical park's three units are provided in Appendix B, which also includes scientific names for bird species mentioned in tables throughout this assessment. This assessment is based on two indicators with a total of

Photo of a Lucy's warbler, a species of concern and a common breeding bird in Tumacácori NHP. Photo Credit: © Robert Shantz.

five measures. The indicators are species occurrence (two measures) and three measures of health.

The first measure of species occurrence is richness and compositon. Richness and composition respresent two different aspects of community dynamics. Richness and composition were evaluated using data from two studies, the most recent of which was part of SODN's monitoring program. SODN conducted avian surveys at 14 points along the Santa Cruz River from 2007 to 2015 (surveys were not done in 2014). The 14 points were equally divided between two riparian transects. Although point count locations may have changed slightly over time, all points were established in riparian habitat (see Beaupré et al. 2013 for the most current survey locations). Each point was generally surveyed twice annually during April and May with slight variation in timing and number of visits for some years (Beaupré et al. 2013). Points were spaced a minimum of 250 m (76 ft) apart. At each point an observer recorded all species heard and/or observed along with an estimated distance to each bird for future density estimates (Beaupré et al 2013). Surveys began approximately 30 minutes before local sunrise and lasted for six minutes at each point (Beaupré et al. 2013).

We reported species richness and abundance by year as well as a list of the 20 most commonly detected species over all survey years as a percentage of total detections. Because points were surveyed twice annually, abundance represents the number of detections and not necessarily the number of individuals (i.e., the same individual may have been detected on both annual visits). We did not analyze trends in abundance because data were not adjusted for variable detection (Beaupré et al. 2013). Flyovers were excluded from the final dataset. Data were provided by K. Bonebrake, SODN data manager on 16 November 2017 via e-mail.

We compared SODN data (2007-2015) to data collected during the 2001-2003 vascular plant and vertebrate inventory (Powell et al. 2005). Powell et al. (2005) surveyed birds using a variety of methods designed to capture nocturnal, resident, and breeding species. Because SODN monitoring efforts focused on the breeding season, we restricted our comparison to breeding season survey data presented in Powell et al. (2005).

Powell et al. (2005) used the Variable Circular Plot (VCP) method to survey breeding birds at eight point count locations along one transect during April through July. The points classified as mesquite bosque, riparian, or developed but were located in similar locations to SODN's point count stations (Powell et al. 2005, Beaupré et al. 2013). Therefore, the data for those three habitat types were combined in order to compare with SODN's data.

The VCP method was similar to SODN protocol in that points were spaced 250 m (76 ft) apart and birds were surveyed for roughly the same time at each point count station (two additional minutes for VCP surveys) (Powell et al. 2005). As with SODN data, flyovers were eliminated. Additionally, birds beyond 75 m (246 ft) from each point count station were also excluded (Powell et al. 2005). To assess bird community stability we determined which species were detected during the earlier surveys (2001-2003) that were not detected by SODN (2007-2015).

The second measure of species occurrence is the presence of species of concern. We cross-referenced the Arizona Partners in Flight (AZ-PIF) Bird Conservation Plan list of priority species of concern (Latta et al. 1999) with the NPSpecies lists for the park (NPS 2017a) and SODN monitoring data. In the Bird Conservation Plan, 43 species of concern were identified for the state (Latta et al. 1999). The list was based on 11 criteria, which included relative abundance, breeding and wintering distribution, threats, and importance of Arizona to the each species (Latta et al. 1999).

We also describe survey results for two federally listed species. The western population of the yellow-billed cuckoo (*Coccyzus americanus*) is listed as threatened and the southwestern willow flycatcher (*Empidonax traillii extimus*) is listed as endangered by the U.S. Fish and Wildlife Service's Endangered Species Program (USFWS 2017). The Santa Cruz River flowing through the park is designated as critical habitat for the southwestern willow flycatcher (USFWS 2013), but critical habitat for the yellow-billed cuckoo has not been identified by the U.S. Fish and Wildlife Service (USFWS 2017). Surveys for the yellow-billed cuckoo were conducted during May-July of 2009 and 2010 and in 2010 only for the southwestern willow flycatcher (Krebbs et al. 2010). Surveys were conducted along the Santa Cruz River in the Tumacácori Unit using call playback and nest searches (Krebbs et al. 2010). Due to the sensitive nature of threatened and endangered species, specific location information was not included in this assessment.

The first measure of bird health for the park is the presence of avian pox. Since 1997 the Institute for Bird Populations has banded songbirds along the Santa Cruz River in Tumacácori NHP as part of the MAPS program (Monitoring Avian Productivity and Survivorship) (Kirkpatrick et al. 2009a). During banding operations, researchers noticed what appeared to be an increased prevalence of lesions on birds' bills, feet, and eyes that resembled avian pox (Kirkpatrick et al. 2009a). Avian pox is a viral disease transmitted to birds most often by biting insects (van Riper and Forrester 2008).

The proportion of adult birds captured from April through July of 2008 and 2009 exhibiting deformities, lesions, or other abnormalities was documented (Kirkpatrick et al. 2009a). Tissue samples from potential avian pox lesions were collected from a subset of these individuals and tested for avian pox (Kirkpatrick et al. 2009a). Nestlings of two migrant species (yellow-breasted chat [*Icteria virens*] and Bell's vireo [*Vireo bellii*]) and one resident species (Abert's towhee [*Melozone aberti*]) were monitored for lesions and samples were collected from those exhibiting signs of active avian pox.

As a control site, adults and nestlings were also monitored for pox and other deformities along Cienega Creek in Cienega Creek Preserve, which is located 63 km (39 mi) northeast of Tumacácori NHP. Cienega Creek is a designated as "outstanding state water resource" by the Arizona Department of Environmental Quality (ADEQ 2017). At Cienega Creek, birds were monitored during 2008 only.

The second measure of health is the presence of heavy metals. The perennial flow of water in Santa Cruz River flowing north through the park was restored in the mid-1900s when Nogales International Wastewater Treatment Plant (NIWTP) began treating and releasing effluent to the river (NPS 2014b). Treated wastewater originates from Nogales, Arizona and Nogales, Sonora, Mexico. The Santa Cruz River is also fed by intermittent tributaries that flow through urban and abandoned mining areas (e.g., Sonoita Creek) (van Riper and Lester 2016). While the restoration of perennially flowing water through the park has restored riparian vegetation with positive effects on the bird community, it has also raised concerns regarding water quality (Kirkpatrick et al. 2009a, van Riper and Lester 2016).

Observations of a possible avian pox outbreak were hypothesized to be influenced by heavy metals (Kirkpatrick et al. 2009a). In April through July 2008 and 2009, Kirkpatrick et al. (2009a) collected feather and blood samples from Abert's towhees and yellow-breasted chats captured at the park's MAPS station and analyzed them for a suite of heavy metals. The heavy metals tested for were arsenic (As), cadmium (Cd), Chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), selenium (Se), strontium (Sr), lead (Pb), and zinc (Zn). Although As and Se are not heavy metals, they are included here for simplicity. These results were compared to blood and feather samples collected from the same species at the control site along Cienega Creek, which was surveyed in 2008 (Kirkpatrick et al. 2009a). Soil samples from the river and the floodplain were also collected in both study areas during October to December 2008. Independent t-tests at a significance level of $p = 0.05$ were used to test for differences between the two study sites (Kirkpatrick et al. 2009a).

In a separate study, eight heavy metals were tested in resident song sparrows (*Melospiza melodia*) (blood and feathers) along the park's riparian corridor during April-June 2011 and July and August 2012 (Lester and van Riper 2014, van Riper and Lester 2016). The metals were Cd, Cr, Cu, Hg, Ni, Pb, Se, and Zn. As with the previous study, Lester and van Riper (2014) compared the results for Tumacácori NHP to a control site. The control site was located along the headwaters of the Santa Cruz River in San Rafael State Natural Area. Because the site was near the headwaters of the Santa Cruz River, it was expected to exhibit low heavy metal concentrations (Lester and van Riper 2014). Two- and three-way ANOVA (ANalysis Of VAriance) were used to test for significant differences among sites for blood and feather samples, respectively. Sex was a main factor and feather age was included as a main factor in the feather analysis (Lester and van Riper 2014).

Finally, the third measure of avian health is reproductive success. Because avian pox and/or heavy metals may affect avian reproductive health, the nests of yellow-breasted chats, Bell's vireos, and Abert's towhees were monitored at the historical park (2008 and 2009) and at Cienega Creek (2008) (Kirkpatrick et al. 2009a). Nests for these three species were also monitored at the Cienega Creek control site in 2008. Nests were monitored every two days until they either fledged or failed. The author's compared average clutch size, egg volume, hatching success, and daily nest survival between the two study areas (Kirkpatrick et al. 2009a). Independent t-tests at a significance level of $p = 0.1$ were used to test for differences in reproductive variables between the two study sites.

Reference Conditions

Reference conditions for the five measures are shown in Table 42. Reference conditions are described for resources in good, moderate concern, and significant concern conditions for the two measures of species occurrence. For the three measures of bird health, moderate concern and significant concern conditions were combined.

Condition and Trend

According to NPSpecies, 182 species are confirmed for the NHP. An additional 29 species are unconfirmed (23), considered probably present (2), or were reported by SODN (4) but not entered into NPSpecies (Appendix B). In total, there may be as many as 211 species for the NHP. This includes four non-native species. These were Eurasian collared-dove (*Streptopelia decaocto*), European starling (*Sturnus vulgaris*), rock pigeon (*Columba livia*), and house sparrow (*Passer domesticus*). All four non-native species breed in the park. Eurasian collared-dove is considered uncommon and occurs year-round.

During SODN's surveys (2007-2015), richness was relatively stable over time while abundance seemed to decline (Figure 17). This may be due to wildfire activity in the riparian area, which is not adapted to fire (NPS 2014a). Across all years, 133 species were observed in riparian habitat. The 20 most commonly detected species in along the riparian transect comprised 70% of all detections across all years of surveys. Gila

Table 42. Reference conditions used to assess birds.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Species Occurrence	Richness and Composition	We considered the condition good if all or nearly all of the species recorded during early surveys/observations in the park were recorded by SODN.	Condition is of moderate concern if several bird species recorded during early surveys in the park were not recorded by SODN (particularly if the species had previously been considered common in the park).	Condition is of significant concern if a substantial number of species recorded during early surveys in the park were not recorded by SODN (particularly if the species had previously been considered common in the park).
	Species of Concern	A moderate to substantial number of species of conservation concern occur in the park, which indicates that the NPS unit provides important habitat for these species and contributes to their conservation.	A small number of species of conservation concern occur in the park.	No species identified as species of conservation concern have been recorded in the park.
Health	Prevalence of Avian Pox	Avian pox is not present or is at or below the average rate of infection for North America.	The proportion of birds exhibiting signs of avian pox exceeds the average rate of infection for North America.	The proportion of birds exhibiting signs of avian pox exceeds the average rate of infection for North America.
	Presence of Heavy Metals	Heavy metals are below the threshold of detectability or are similar to levels in blood and feather samples collected from reference/control sites.	Heavy metals exceed levels in blood and feather samples collected from reference/ control sites.	Heavy metals exceed levels in blood and feather samples collected from reference/ control sites.
	Reproductive Health	Egg volume, clutch size, and hatching success are similar to or better than the reference/ control site.	Egg volume, clutch size, and hatching success are significantly lower than the reference/control site.	Egg volume, clutch size, and hatching success are significantly lower than the reference/control site.

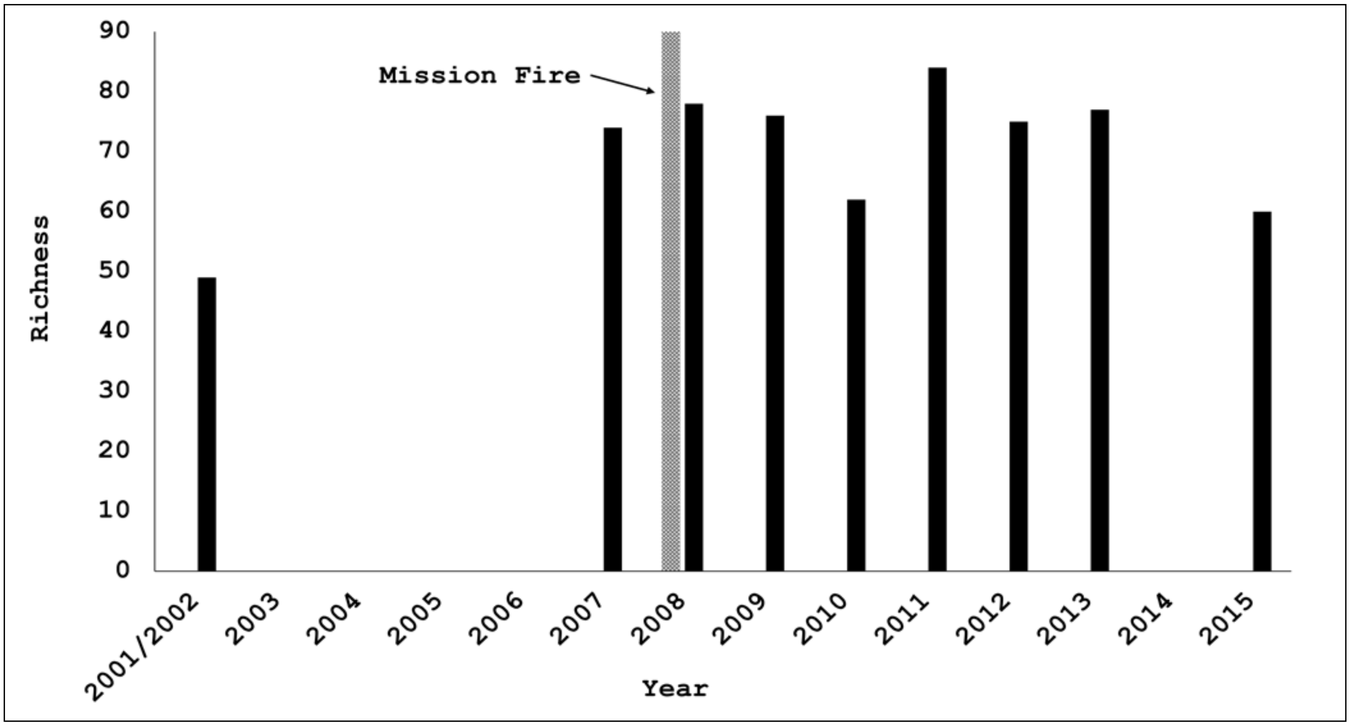


Figure 17. **Richness and abundance by year and habitat type in Tumacácori NHP.**

woodpecker (*Melanerpes uropygialis*), Lucy's warbler (*Oreothlypis luciae*), and Bewick's wren (*Thryomanes bewickii*) were among the most commonly observed species. Five of these species are riparian obligates, or species that requiring riparian habitat for breeding (shown in bold in Table 43). All four non-native species were detected during SODN surveys, but none of them were among the top 20 most commonly detected species.

During 2001-2002, a total of 49 species were observed across riparian, mesquite bosque, and developed areas (Powell et al. 2005). No species were reported during the earlier VCP surveys that were not reported during 2007-2015. Overall, these results indicate few changes to the bird community from the earlier surveys (Powell et al. 2005) to the more recent SODN surveys. Although four non-native species occur in the park, overall richness appears good and the most common species are representative of riparian communities in the region. For these reasons, the condition for this measure is good. Confidence is high because the two studies employed similar, standardized methods and occurred during the breeding season. Although richness and composition appear stable, there were not enough data to assess trends over time.

Table 43. **The 20 most commonly detected species at Tumacácori NHP during 2007 to 2015.**

Common Name	Proportion of All Detections
Gila woodpecker	6.52
Lucy's warbler	5.77
Bewick's wren	5.61
White-winged dove	5.19
Brown-crested flycatcher	4.96
Summer tanager	3.77
Phainopepla	3.68
House finch	3.55
Yellow-breasted chat*	3.40
Yellow warbler*	3.28
Lark sparrow	3.08
Vermilion flycatcher	2.86
Lesser goldfinch	2.71
Northern cardinal	2.70
Brown-headed cowbird	2.64
Cassin's kingbird	2.44
Mourning dove	2.35
Bell's vireo*	2.07
Song sparrow*	1.88
Gray hawk*	1.67

* Species are considered riparian obligate species (Guzy and Ritchison 1999, Lowther et al. 1999, Eckerle and Thompson 2001, Bibles et al. 2002, Kus et al. 2010).

For the species of conservation concern measure, we found that 21 of the 43 species listed as priority species of conservation concern in the Arizona Partners in Flight Bird Conservation Plan Version 1.0 are known to occur or potentially occur in the park (Table 44) (Latta et al. 1999). Although NPSpecies listed five of these species as either unconfirmed or probably present, Powell et al. (2005) reported four of the five species as occurring in the park (sagebrush sparrow [*Amphispiza nevadensis*] was not reported). Of the 14 species that were assigned an annual status, eight are considered migratory, five are considered breeders, and one is considered resident.

Table 44. Arizona Partners in Flight bird species of conservation concern occurring in Tumacácori NHP.

Common Name	NPSpecies Abundance	NPSpecies Annual Status
Band-tailed pigeon	Unconfirmed	Unconfirmed
Black-throated gray warbler	Uncommon	Migratory
Brewer's sparrow	Common	Resident
Cassin's sparrow	Rare	Migratory
Common black hawk	Uncommon	Migratory
Cordilleran flycatcher	Unconfirmed	Unconfirmed
Costa's hummingbird	Rare	Migratory
Elegant trogon	Unconfirmed	Unconfirmed
Gilded flicker	Uncommon	Breeder
Gray vireo	Rare	Migratory
Lucy's warbler	Common	Breeder
MacGillivray's Warbler	Uncommon	Migratory
Montezuma Quail	Unconfirmed	Unconfirmed
Olive-sided Flycatcher	Rare	Migratory
Purple Martin	Uncommon	Breeder
Rufous-winged Sparrow	Common	Breeder
Sagebrush/Bell's Sparrow[1]	Unconfirmed	Unconfirmed
Swainson's Thrush	Rare	Migratory
Willow Flycatcher[2]	Probably Present	Probably Present
Yellow-billed Cuckoo[3]	Uncommon	Breeder

[1] Formerly known as sage sparrow (*Amphispiza belli*), this species was split into two species: Bell's vireo (*A. belli*) and sagebrush sparrow (*A nevadensis)*. NPSpecies lists sage sparrow. Both species may occur in the park (Martin and Carlson 1998, AOS 2017).

[2] The southwestern subspecies (*E. t. extimus*) is listed by the U.S. Fish and Wildlife as endangered (USFWS 2017). Subspecies was listed by Powell et al. (2005).

[3] The western distinct population, which includes Arizona, is listed as threatened by U.S. Fish and Wildlife Service (USFWS 2017).

No southwestern willow flycatchers were detected during 2010 surveys (Krebbs et al. 2010). Krebbs et al. (2010) suggested that removal of tamarisk (*Tamarix ramosissima*) coincident with the 2010 flycatcher surveys may have impacted their presence in the park; however, the species and subspecies appears to be rare at Tumacácori NHP. Willow flycatcher was listed by NPSpecies as probably present with no annual status (NPS 2017a). Powell et al. (2005) reported only four individuals, one of which was identified as the endangered southwestern subspecies, and none were detected during 2007-2015 SODN surveys.

During 2009 surveys for the yellow-billed cuckoo there were 33 responses to call playback surveys, 6 individuals observed, and one confirmed nest (Krebbs et al. 2010). In 2010 there were 65 responses to call playback surveys, 21 observed individuals, and two possible nest locations (Krebbs et al. 2010). Krebbs et al. (2010) estimated that at least 11 pairs of cuckoos occurred in the park. These results were lower than those reported by Powell (2000) as cited in Krebbs et al. (2010). Krebbs et al. (2010) speculated fewer yellow-billed cuckoos during the 2009-2010 surveys may be a result of the 2008 Mission Fire, which burned nesting habitat. During the 2001-2003 bio-inventory, four yellow-billed cuckoo detections were reported (Powell et al. 2005) and six detections were reported during 2007 and 2008 SODN surveys but not during later years. Neither the bio-inventory nor SODN surveys specifically targeted yellow-billed cuckoos. The substantially higher number of individuals reported during targeted surveys highlights the importance of focused efforts for rare and/or secretive species such as the yellow-billed cuckoo.

Since 14 of the 43 species of conservation concern (33%) are confirmed for the park, including federally threatened and endangered species, the condition is good. Confidence in the presence/absence of these species is high, but there are uncertainties regarding status for some species (e.g., southwestern willow flycatcher). The trend for this measure is unknown.

The presence of avian pox was assessed by examining adults and nestlings for physical deformities as well as testing tissue samples from potentially infected birds. Physical deformities among adult riparian birds in Tumacácori NHP were conservatively estimated at 4% in 2008 and 3% in 2009 (Kirkpatrick et al. 2009a). These estimates are conservative because they exclude birds whose deformities could have been due to accidental injury or previous disease rather than avian pox. Deformities were observed for yellow-breasted chats, Bewick's wrens, Lucy's warblers, northern cardinals (*Cardinalis cardinalis*), and Abert's towhees (Table 45). Deformities in adult birds were not observed at the Cienega Creek control site.

Of the 147 nestlings examined at Tumacácori NHP in 2008, three individuals (2%) exhibited deformities, all of which were yellow-breasted chats. There were no deformities found in the 54 nestlings observed at the control site. In 2009, only one of 137 nestlings (0.7%) examined at Tumacácori NHP exhibited deformities. However, none of the deformities observed in either year were described as pox-like lesions (Kirkpatrick et al. 2009a). Nestlings were not examined at the control site in 2009.

Tissue samples collected from a single adult Lucy's warbler and an adult Bewick's wren tested negative for avian pox (Kirkpatrick et al. 2009a). Tissue samples were collected from only two individuals because they were the only birds that exhibited fresh pox-like lesions. Although other individuals exhibited pox-like lesions, the lesions were either inactive or too small to sample (Kirkpatrick et al. 2009a). These results indicate a possible previous outbreak of avian pox that was no longer active by 2008. Nevertheless, the rate of deformities was higher than the average rate among birds elsewhere, which is considered to be <1% according to the Royal Society for the Protection of Birds (2007). The 1% rate is a conservative comparison since it includes deformities that are not associated with avian pox, such as genetic defects or healed broken legs. Therefore, the results for Tumacácori NHP warrant moderate/significant concern, but confidence is low since the data were 10 years old and may not reflect current condition. Trend could not be determined.

Table 45. Proportion of adult birds exhibiting pox-like lesions in 2008 and 2009.

Species	% (# individuals)	
	2008	2009
Abert's towhee	0 (13)	6 (17)
Bell's vireo	0 (3)	0 (6)
Bewick's wren	6 (16)	5 (20)
Lucy's warbler	12 (8)	0 (21)
Northern cardinal	0 (9)	0 (6)
Song sparrow	0 (3)	0 (7)
Verdin	0 (1)	–
Yellow-breasted chat	6 (36)	3 (70)
Average (Total)	4 (89)	3 (147)

Note: Data excludes deformities that could have been due to accidental injury or previous disease.

Source: Data were extracted from Kirkpatrick et al. (2009a).

The presence of heavy metals was assessed in both the environment and in blood samples. Soil samples collected in 2008-2009 from the Santa Cruz River sediment and floodplain had higher levels of several heavy metals compared to the Cienega Creek control site (Table 46). In river sediment the elevated metals were Cd, Cu, Pb, and Zn. In the floodplain the elevated metals were Cd, Cr, Cu, Hg, Pb, and Zn. Although heavy metals were elevated in soil samples, blood and feather samples from birds surveyed did not exhibit elevated levels of these metals in the park, and there was no difference in heavy metals between the two study sites, except for Se, which was twice as high in yellow-breasted chats at the control site (t = 7.0, p = 0.010, Tables 47 and 48). The sample sizes, however, were small: between two and four individuals were sampled per study site.

Photo of a northern cardinal. Photo Credit: © Robert Shantz.

Table 46. Heavy metal concentration (ppm) and standard error (in parentheses) in soils at Tumacácori NHP and at the Cienega Creek control site in 2008.

Metal	River Sediment				Floodplain Soil			
	Cienega Creek	Tumacácori NHP	*t*	*P*	Cienega Creek	Tumacácori NHP	*t*	*P*
Arsenic (As)	7.12 (1.00)	6.08 (0.57)	0.90	0.201	7.24 (0.65)	8.95 (1.19)	-1.27	0.126
Cadmium (Cd)	0.04 (0.02)*	1.34 (0.14)*	-9.25*	0.000*	0.09 (0.01)*	0.45 (0.08)*	-4.46*	0.006*
Chromium (Cr)	10.50 (1.39)	9.09 (0.79)	0.88	0.206	10.85 (0.59)*	13.27 (0.98)*	-2.11*	0.036*
Copper (Cu)	18.31 (2.26)*	30.40 (2.26)*	-3.79*	0.003*	23.06 (2.94)*	49.09 (9.93)*	-2.51*	0.027*
Mercury (Hg)	0.01 (0.01)	0.00 (0.00)	1.24	0.141	0.01 (0.00)*	0.02 (0.01)*	-2.78*	0.014*
Nickle (Ni)	10.52 (1.12)	9.74 (0.66)	0.60	0.285	11.30 (0.59)	11.84 (1.39)	-0.35	0.370
Selenium (Se)	Not Detected	0.00 (0.00)	–	–	Not Detected	0.00 (0.00)	–	–
Lead (Pb)	16.54 (1.20)*	20.34 (1.35)*	-2.10*	0.034*	18.41 (0.97)*	52.65 (15.54)*	-2.35*	0.039*
Zinc (Zn)	37.06 (2.33)*	64.65 (4.62)*	-5.35*	0.001*	40.80 (2.61)*	88.51 (13.81)*	-3.40*	0.014*

* Values indicate significant differences.

Source: Data were extracted from Kirkpatrick et al. (2009a).

Table 47. Mean (ppm) and standard error (in parentheses) of ten heavy metals found bird feather samples at Tumacácori NHP and at the Cienega Creek control in 2008 and 2009.

Metal	Abert's Towhee		Yellow-breasted Chat	
	Cienega Creek (n = 2)	Tumacácori NHP (n = 3)	Cienega Creek (n = 3)	Tumacácori NHP (n = 6)
Arsenic (As)	0.041 (0.003)	0.038 (0.003)	0.054 (0.006)	0.046 (0.005)
Cadmium (Cd)	Not Detected	0.003 (0.0)	Not Detected	Not Detected
Chromium (Cr)	0.059 (0.0)	0.031 (0.0)	0.043 (0.0)	0.058 (0.010)
Copper (Cu)	0.124 (0.005)	0.117 (0.026)	0.640 (0.164)	0.463 (0.029)
Mercury (Hg)	0.552 (0.302)	0.135 (0.033)	–	0.216 (0.036)

Source: Data were extracted from Kirkpatrick et al. (2009a).

Table 48. Mean (ppm) and standard error (in parentheses) of ten heavy metals found bird blood samples at Tumacácori NHP and at the Cienega Creek control in 2008 and 2009.

Metal	Abert's Towhee		Yellow-breasted Chat	
	Cienega Creek (n = 2)	Tumacácori NHP (n = 3)	Cienega Creek (n = 3)	Tumacácori NHP (n = 4)
Mercury (Hg)	0.052 (0.014)	0.021 (0.008)	0.048 (0.010)	0.023 (0.006)
Nickle (Ni)	0.127 (0.058)	0.020 (0.002)	0.145 (0.063)	0.084 (0.034)
Lead (Pb)	0.019 (0.003)	0.022 (0.003)	0.015 (0.001)	0.019 (0.003)
Selenium (Se)	0.823 (0.154)	0.470 (0.015)	1.049 (0.079)*	0.476 (0.021)*
Strontium (Sr)	0.053 (0.001)	0.062 (0.013)	0.075 (0.009)	0.123 (0.056)
Zinc (Zn)	4.29 (0.19)	4.37 (0.11)	6.18 (0.69)	6.35 (0.45)

* Values indicate significant differences.

Source: Data were extracted from Kirkpatrick et al. (2009a).

Of the eight heavy metals tested in song sparrow feather and blood samples collected during 2011 and 2012, three exhibited significant differences between Tumacácori NHP and the control site (Tables 49 and 50). Cd was greater in both feather and blood samples in Tumacácori NHP than the control site. Pb was greater in feather but not blood samples collected from Tumacácori NHP, and Hg was lower in feathers from Tumacácori. When comparing samples from 33 recaptured song sparrows at Tumacácori NHP, there was a significant increase in five heavy metals between 2011 and 2012 (Cd, Cu, Hg, Pb, and Zn), while Ni was significantly lower in 2012 than during 2011 ($p < 0.05$). These results suggest possible bioaccumulation over time (Lester and van Riper 2014).

Table 49. Mean (ppm) and standard error (in parentheses) of heavy metals found in song sparrow feather samples during 2011 and 2012.

Metal	Control Site *n* = 39	Tumacácori NHP *n* = 39
Cadmium (Cd)	0.109 (0.012)*	0.422 (0.035)*
Chromium (Cr)	0.418 (0.108)	0.364 (0.027)
Copper (Cu)	11.69 (0.860)	10.73 (0.422)
Mercury (Hg)	0.251 (0.089)*	0.221 (0.041)*
Nickle (Ni)	1.223 (0.231)	1.323 (0.213)
Lead (Pb)	0.706 (0.061)*	1.050 (0.070)*
Selenium (Se)	0.984 (0.095)	0.648 (0.078)
Zinc (Zn)	195.1 (11.52)	171.6 (5.488)

* Indicates significantly different ($p < 0.05$) from control site.

Source: Data were extracted from Lester and van Riper (2014).

Table 50. Mean (ppm) and standard error (in parentheses) of heavy metals found in song sparrow blood samples during 2011 and 2012.

Metal	Control Site *n* = 40	Tumacácori NHP *n* = 37
Cadmium (Cd)	0.002 (0.0002)*	0.004 (0.0004)*
Chromium (Cr)	0.035 (0.009)	0.018 (0.002)
Copper (Cu)	0.672 (0.050)	0.740 (0.072)
Mercury (Hg)	0.058 (0.015)	0.065 (0.014)
Nickle (Ni)	0.136 (0.120)	0.025 (0.007)
Lead (Pb)	0.041 (0.121)	0.027 (0.004)
Selenium (Se)	2.493 (0.190)	3.364 (0.424)
Zinc (Zn)	7.132 (0.540)	8.219 (0.803)

* Indicates significantly different ($p < 0.05$) from control site.

Source: Data were extracted from Lester and van Riper (2014).

In general however, heavy metal concentrations in song sparrows were lower in the park than elsewhere in the Santa Cruz River watershed (see Lester and van Riper 2014 for comparison to locations other than the control site presented in this assessment). However, song sparrows did exhibit elevated levels of mercury and nickle compared to other locations in the watershed (Lester and van Riper 2014). Historical gold mining in the Patagonia Mountains is the likely source since mercury is used to extract gold from ore, and the higher nickle concentrations are likely sourced from NIWTP (van Riper and Lester 2016).

When comparing the results for song sparrows collected in 2011-2012 to the 2008-2009 study, Cr and Ni concentrations in song sparrow blood samples were lower than concentrations of these metals in Abert's towhees and yellow-breasted chats, with Cr exhibiting the only significant decrease (Wilcox test = 142; $p \leq 0.01$). Cd showed similar concentrations between towhees and sparrows, but chats were below detection limits. Pb, Cu, and Zn concentrations were only slightly higher in song sparrows, whereas Hg and Se were two to six times higher in song sparrows compared to towhees and chats (refer to figure 2 in van Riper and Lester 2016). For most heavy metals, concentrations were lower in 2011-2012 than during 2008-2009 (van Riper and Lester 2016). A 2009 upgrade at NIWTP may be responsible for lower heavy metal concentrations between the two studies (Lester and Van Riper 2014).

Although several metals reported by van Riper and Lester (2016) exceeded control site levels in the park, the author's reported that existing levels were not toxic. The authors also reported no evidence to suggest adverse effects of metals on song sparrows. Tests of hematocrit values, white blood cell counts, and blood parasites, which can all be altered by heavy metals, were within the range of normal (Lester and van Riper 2014).

Furthermore, trends in heavy metals have apparently improved over time following the upgrade to the NIWTP (van Riper and Lester 2016). Overall, these results suggest that current levels of heavy metals do not pose a health risk for birds in Tumacácori NHP. Therefore, the condition for this measure is good but confidence is low because the data are more than five years old.

For the last measure of health, observers located and monitored 59 yellow-breasted chat nests, 37 Bell's vireo nests, and 25 Abert's towhee nests across the two study sites in 2008 (Tumacácori NHP and Cienega Creek). There were too few Bell's vireo nests to assess differences in clutch size, hatching success, or nesting success between the two study sites. There were no differences in clutch size (Table 51) or egg volume

Table 51. Clutch size for three species.

Species	Cienega Creek	Tumacácori NHP
Abert's towhee	3.0 (SE 0.0, *n* = 5)	2.92 (SE 0.1, *n* = 12)
Bell's vireo	3.3 (SE = 0.1, *n* = 12)	3.0 (SE = 0.0, *n* = 2)
Yellow-breasted chat	3.8 (SE = 0.2, *n* = 6)	3.5 (SE = 0.1, *n* = 39)

Source: Data were extracted from Kirkpatrick et al. (2009a).

(Figure 18) by species between the two study sites; however, chats exhibited a small but significantly higher hatching success at Tumacácori NHP than at the control site (Figures 18 and 19; nesting). Chat nesting success was also greater at Tumacácori NHP than at the control site ($Z = 2.6$, $p = 0.009$), but no differences were detected for towhees.

These results suggest that neither the effects of a previous avian pox outbreak or elevated levels of heavy metals had influenced reproductive health at Tumacácori NHP, at least for chats and towhees. There were too few data for conclusions regarding vireos. For all reproductive variables however, sample sizes were small due to the large proportion of nests that were parasitized by brown-headed cowbirds (*Molothrus ater*), and results should be interpreted with caution. Based on the available data, the condition for reproductive health is good at Tumacácori NHP, but confidence is low because the data were collected ten years ago. Trend could not be determined.

Photo of an Abert's Towhee. Photo Credit: © Robert Shantz.

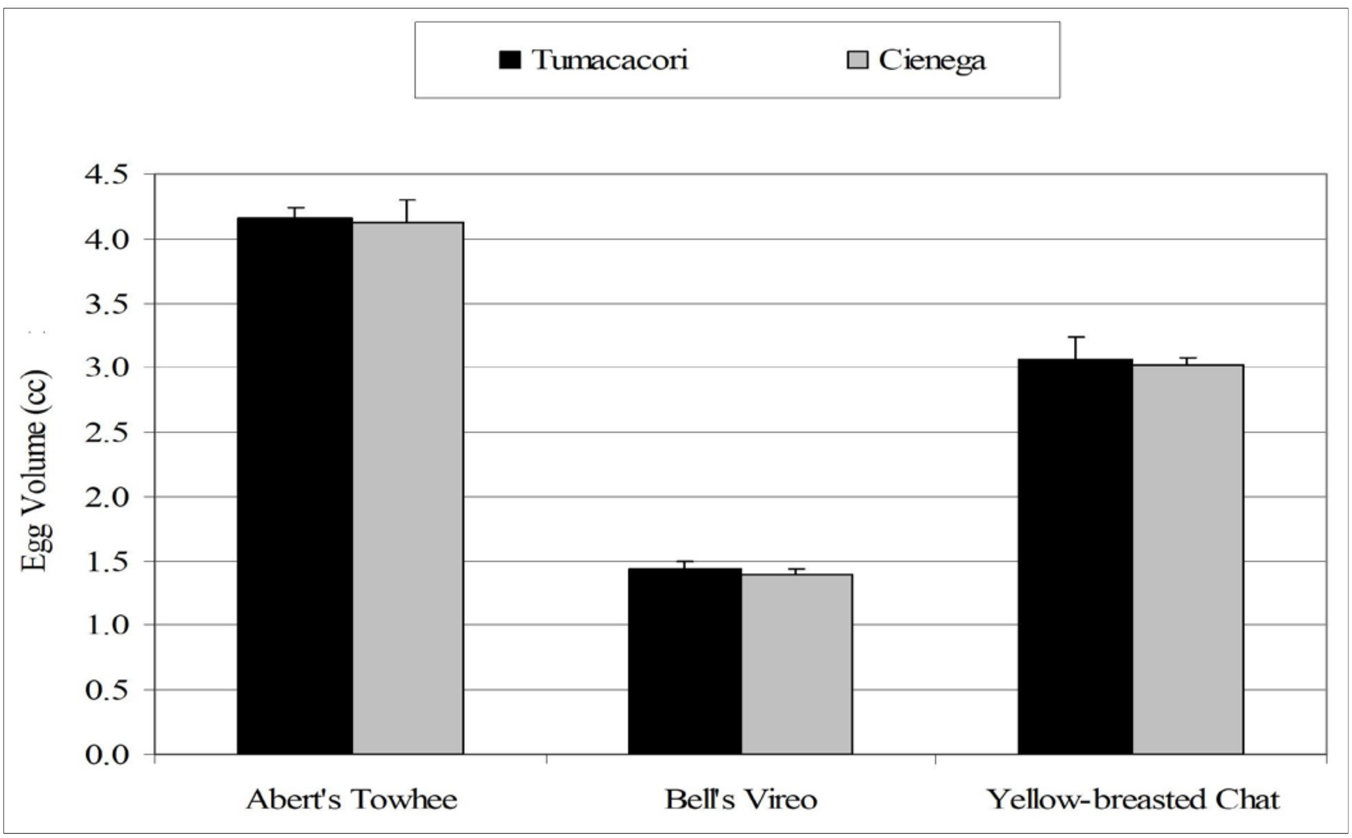


Figure 18. Egg volume for Abert's towhee, Bell's vireo, and yellow-breasted chat. Figure Credit: © Kirkpatrick et al. 2009a.

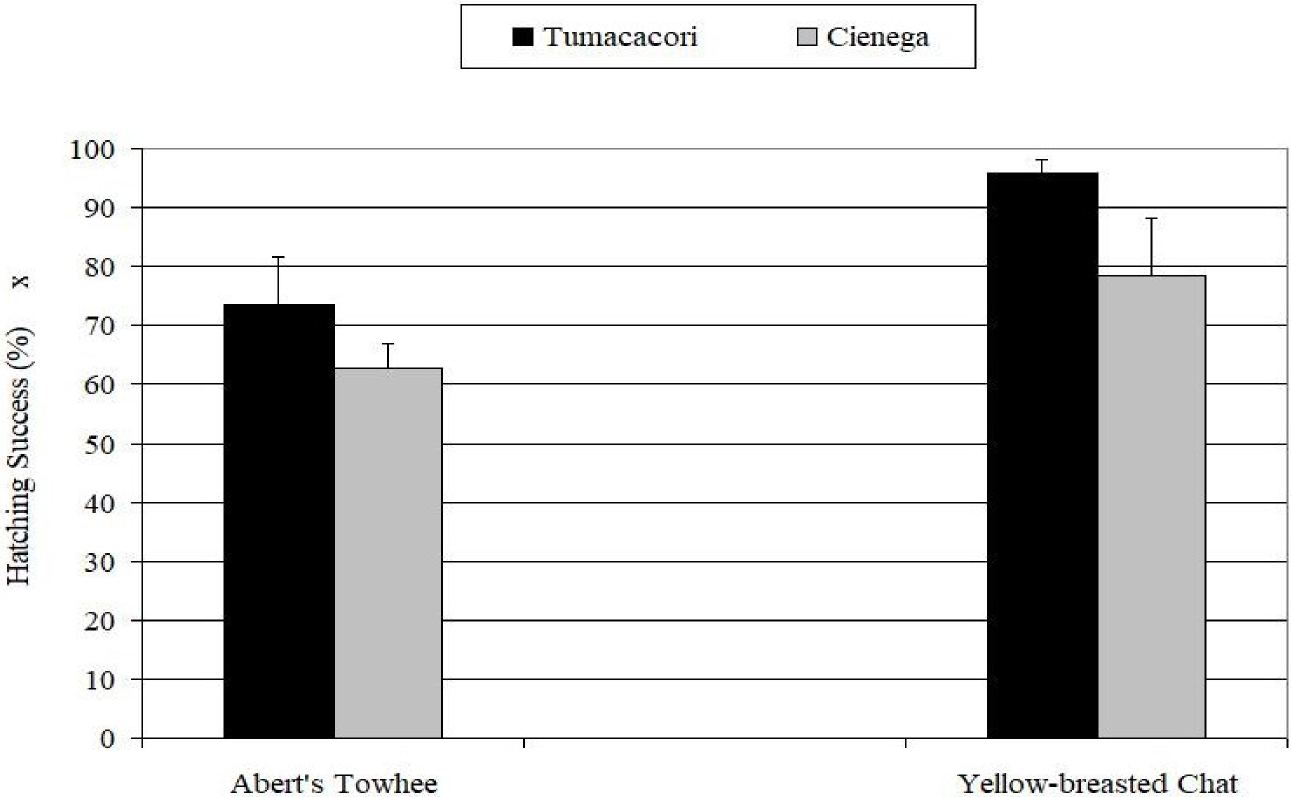


Figure 19. Hatching success for Abert's towhee and yellow-breasted chat. Figure Credit: © Kirkpatrick et al. 2009a.

Overall Condition, Threats, and Data Gaps

We used two indicators and five measures (summarized in Table 52) to assess the condition of birds at Tumacácori NHP. Despite its small size, the park's avifauna is diverse, native species richness is high, and species composition reflects the vegetative communities that the park provides. In this assessment, all but one measure was assigned good condition, but because the confidence was low due to the age of the data, it did not contribute significantly into the overall condition rating. Measures with high confidence weigh more heavily into the overall condition rating than measures with medium or low confidence. The two measures of species occurrence were assigned high confidence and good condition, while the remaining two health measures were assigned good condition but with low confidence. This resulted in an overall condition of good and a confidence level of medium. We could not determine trend based on the available data.

A key uncertainty is how abundance for certain species has changed over time, particularly for species of concern and those relying on specific habitat types. Inferences regarding changes in abundance are confounded by potential differences in annual detectability (Beaupré et al. 2013). Without a corresponding detectability analysis, changes in abundance could not be determined and was beyond the scope of this assessment. An additional key uncertainty is that the AZ-PIF Bird Conservation Plan has not been updated since 1999 and may not reflect the current suite of species of concern for Arizona.

Migratory and other bird species face threats throughout their ranges, including: loss or degradation of habitat due to development, agriculture, and forestry activities; collisions with vehicles and man-made structures (e.g., buildings, wind turbines, communication towers, and electrical lines); poisoning; and landscape changes due to climate change (USFWS 2016). The federal Migratory Bird Treaty Act protects more than 1,000 species of bird, and many of these species are experiencing population declines because of increased threats within their range (USFWS 2016). Also, across the U.S., free-ranging domestic cats (*Felis catus*) may be responsible for as many as one billion bird deaths each year (Wildlife Society 2011, Loss et al.

Table 52. Summary of birds indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Richness and Composition		A total of 186 species occur in the historical park (including species listed by SODN but not NPSpecies). Native species richness is high and species composition reflects the riparian plant communities that the park provides. Overall and based on available data, there have been few changes to the bird community, except the introduction of four non-native species. For these reasons, this measure is in good condition with high confidence. Although species composition and richness appears stable, there were not enough data to fully assess trends.
	Species of Conservation Concern		Since 14 of the 43 species of conservation concern (33%) are confirmed for the park, the condition is good. Confidence in the presence/absence of these species is high, but there are uncertainties regarding status for some species (e.g., southwestern willow flycatcher). The trend for this measure is unknown.
Health	Presence of Avian Pox		Between 3% and 4% of birds banded in 2008 and 2008 exhibited pox-like lesions, but the two lesions sampled tested negative for the disease. The results indicate a previous pox outbreak. The deformity rates were greater than the 1% average that is estimated for healthy bird populations. For these reasons, this measure warrants moderate to significant concern, but confidence is low because the data are 10 years old and no virus was found in the existing lesions. Trend could not be determined.
	Presence of Heavy Metals		Although some heavy metals were elevated in riparian sediment and floodplain soils, none of them exhibited elevated levels in birds at the park during 2008 and 2009. In 2011-2012, several heavy metals were higher in song sparrow blood and feather samples than at a control site. The concentrations observed, however, appeared to be insignificant to bird health. Confidence is low because the data are 5-10 years old. Trends could not be determined but an upgrade to the water treatment plant has led to better water quality in the park.
	Reproductive Health		Egg volume, clutch size, and hatching success were similar between the control site and Tumacácori NHP. In fact, yellow-breasted chats exhibited higher clutch size and hatching success in the park than at the control site, although ample sizes were small. Although these data indicate that a previous outbreak of pox and the presence of some heavy metals has not had adverse effects on reproductive success for the three species studied, the data are 10 years old and the sample size was small. For these reasons confidence is low. Trend is unknown.
Overall Condition	Summary of All Measures		The two five measures used to assess birds indicate that the condition for this resource is good. The park exhibits high species richness and provides habitat for 33% of the State listed species of concern, including threatened and endangered species. The data used in this assessment also suggest that there have been few changes to the bird community except for the introduction of four non-native species. However, information on changes in abundance, current reproductive success, and current non-breeding season data are lacking. Confidence is high and trends are unknown.

2013). Domestic cats and dogs (*Canis lupus familiaris*) occur in the park (Powell et al. 2005). Other non-native mammals include Virginia opossum (*Didelphis virginiana*) and domestic cattle (*Box taurus*), the latter of which occasionally trespasses into the park's riparian area (Powell et al. 2005). Cattle destroy vegetation, contribute to erosion and soil compaction, and compromise water quality (Powell et al. 2005).

Small parks are especially vulnerable to factors beyond their borders. Because of the historical park's small size and high amount of edge owing to the three separate units, edge effects such as non-native species encroachment may be high. Four human-adapted non-native species of bird have been observed in the park (NPS 2017a), particularly in the park's riparian habitat (Powell et al. 2005). While the specific effects of these introduced species on native birds in the park is unknown, they likely compete with them for nesting habitat, food, and other resources as they do in other areas (Cabe 1993, Lowther and Cink 2006, Romagosa 2012, Lowther and Johnston 2014).

Although brown-headed cowbirds are native, their numbers have increased throughout their range, and their range has expanded in response to agriculture (Lowther 1993). Because they are brood parasites (i.e., lay their eggs in other birds' nests), they can be problematic for other native species such as Bell's vireo, yellow warbler (*Setophaga petechia*), yellow-breasted chat and other species (Powell et al. 2005, Kirkpatrick et al. 2009a). Bronzed cowbirds (*Molothrus aeneus*) are also brood parasites that breed in the park. Bronzed cowbirds are known to parasitize 101 species of bird, including many of the park's breeding species (Ellison and Lowther 2009).

Riparian habitat represents less than 2% (0.5% in Arizona) of the American southwestern landscape but supports more than 50% of the region's bird species (Kirkpatrick et al. 2009b, NPS 2014c). Despite its importance, riparian habitat in Arizona is one of the most imperilled in the state (Latta et al. 1999), primarily as a result of increasing human pressure on water resources and climate change (Shamir et al. 2007). In Tumacácori NHP, riparian vegetation supports more than 150 of the 180 confirmed breeding, wintering, and migratory birds species found in the park (Kirkpatrick et al. 2009a, NPS 2017a).

Maintaining the historical park's riparian habitat depends on regular stream flow. In the mid-1900s, stream flow in the Santa Cruz River was restored with treated wastewater from the NIWTP (NPS 2014b). While the restoration of perennially flowing water has had positive effects on vegetation and wildlife, some heavy metal concentrations were higher than in other areas of the watershed (van Riper and Lester 2014); however, of the 88 water quality variables analyzed by SODN in 2015, none exceeded Arizona state standards (Gwilliam et al. 2016). A new Mexican wastewater treatment plant built in 2012 is responsible for improved water quality, but once again, diminished flows threaten habitat quality in the park. The NIWTP currently discharges ~13-15 mgd into the Santa Cruz River, most of which (9-12 mgd) originates in Mexico (NPS 2014b). An international treaty governs all but 3 mgd of this effluent, and with improved water quality, Mexico now uses approximately half of this water for agriculture and groundwater recharge (NPS 2014b).

The effects of diminished flows in Tumacácori NHP have resulted in no-flow events (NPS 2014b). Although complex riparian vegetation is often cited as the primary factor influencing bird community composition, a study of the effects of ground and surface water on riparian birds in the Santa Cruz River watershed, found that total relative abundance and species richness was positively associated with the presence and extent of surface water, even after controlling for vegetation structure (Kirkpatrick et al. 2009b). This relationship may be partially or entirely explained by arthropod abundance, particularly of the order Diptera, which was greater at wetter sites than at drier sites (Kirkpatrick et al. 2009b). Arthropods are a primary food source for many riparian birds, including common yellowthroat (*Geothlypis trichas*), black phoebe (*Sayornis nigricans*), yellow warbler, and song sparrow among others (Kirkpatrick et al. 2009b).

Maintaining adequate groundwater levels requires constant stream flow and is essential for healthy riparian vegetation and bird communities. If long-term drought conditions persist or increase in Arizona, riparian bird communities will likely decline (Kirkpatrick et al. 2009b). Recent climate conditions in the park and elsewhere in the desert southwest have already shifted beyond the historical range of variability (Prein et al. 2016). In Tumacácori NHP, four temperature variables were categorized as "extreme warm," which was defined as values exceeding 95% of the historical range of conditions (Monahan and Fisichelli 2014). While no precipitation variables were classified as extreme dry, evaporation and transpiration will increase as the temperature warms (NPS 2014b).

Non-native plants are also of concern in the park. Prior to a tamarisk removal project in 2008 (Drake et al. 2009), this invasive species exhibited 1-5% cover across 42% of the park (Studd and Zepp 2009). In one study, black phoebes were negatively associated with tamarisk (Kirkpatrick et al. 2009b), while southwestern willow flycatchers use this species for nesting and foraging (Tucson Audubon Society 2005). Southwestern willow flycatchers, however, are rare in the park, and may not occur there (Powell et al. 2005).

Key data gaps include information on reproductive success for species of concern. While presence/absence and abundance data are valuable, reproductive success can inform whether the protected area of the NHP serve as a source for which to populate other areas outside of their boundaries. Additionally, the majority of surveys have occurred during the breeding season. However, 53% of all species confirmed in the park are migratory or resident. The southern location in the U.S. and relatively low elevation of the park (Beaupré et al. 2013) suggests that the park also provides important wintering habitat for many species.

Finally, this assessment focused on the riparian bird community in the Tumacácori Unit, which is where most surveys have been conducted. However, the Calabazas and Guevavi Units, although smaller than the Tumacácori Unit, support semi-desert grasslands, which may also provide important bird habitat (Powell et al. 2005). Other than the inventory conducted in 2001-2003 (Powell et al. 2005), we are not aware of any other bird surveys in these units. During the inventory and across all survey methods, 80 species were observed in the Calabazas Unit and 74 were observed in the Guevavi Unit (Powell et al. 2005). By comparison, 129 species were observed in the Tumacácori Unit (Powell et al. 2005).

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University.

Mammals

Background and Importance

Tumacácori National Historical Park (NHP) is situated along the upper Santa Cruz River, which sustains one of most ecologically diverse riparian areas in the southwest (King et al. 1999) and has supported human communities for over 3,500 years (Sutherland 2009). The upper Santa Cruz River natural resource communities and associated flora and fauna are integral to the historic and current uses of the area, creating a productive environment for agriculture, pasture land, and habitation. Mammals have contributed to the various settlements in the Santa Cruz Valley serving as a source of subsistence, either from hunting free-roaming wildlife or through domestication. While reliance on hunting has declined significantly since the original settlement of the valley, mammal richness and abundance can serve as indicators to inform ecological conditions and habitat integrity.

Tumacácori NHP's biogeographic location and adjacent regional landscapes influence mammal species diversity, richness, and abundance. Along the upper Santa Cruz River, 29 km (18 mi) north of the Mexico border, the NHP preserves semi-desert grasslands and Sonoran riparian ecosystems that serve as corridors for American and Mexican plant and animal species. The health, distribution, and diversity of mammals that utilize the Santa Cruz River area is important to the park and surrounding region because mammals play a crucial ecosystem role by serving as predators, prey, seed dispersers, and grazers.

Data and Methods

To assess the condition of mammals at Tumacácori NHP, we used one indicator, species occurrence, with a total of three measures: species presence/absence, species nativity, and species of conservation concern. The species presence/absence measure was separated into two groups, small mammals and medium- to large-sized mammals, due to the varying degree of inventory and monitoring efforts devoted to each group at the park.

Tumacácori NHP's baseline inventory for mammals was conducted from 2001 to 2002 using repeatable study designs and standardized field techniques (Powell et al. 2005). The inventory was part of a regional vascular plant and vertebrate effort that included eight Arizona and New Mexico national parks within the National Park Service's (NPS) Sonoran Desert Inventory and Monitoring Network (SODN). Prior to the park's mammalian baseline inventory, two specimens of white-tailed deer (*Odocoileus virginaianus*) were collected in 1964 and 1966 and were most likely struck by vehicles or died of natural causes. No other mammal collections, with

Deer along the Santa Cruz River at Tumacácori NHP. Photo Credit: © P. Christman.

the exception of bats, which will be evaluated in a separate assessment in this report, were made prior to Tumacácori's 2001/2002 baseline inventory.

Mammal captures/recordings within each of Tumacácori's NHP's three units, Calabazas, Guevavi, and Tumacácori, during the baseline inventory, were calculated for species richness and abundance separately, as well as for the entire park. Species abundance of small mammals was analyzed from the number of captures per trap night. Due to prior vegetation survey work at the Tumacácori unit, vegetation structures were classified and determined at each trapping site. Vegetation plot site classifications were applied to the Calabazas and Guevavi units based on similarly observed vegetation characteristics. Species richness was determined using all forms of survey methods to maximize species detection. Wildlife cameras were subjectively placed in areas that would document the most use (i.e. game trails and access to water) in the Tumacácori unit only, where relative abundance of medium- to large-sized mammals was calculated based on total documented species.

Subsequent to the baseline inventory, two camera trap monitoring efforts were implemented at the park. Beginning in November 2010, Welborn and McCallum (2011, 2012) placed infrared cameras throughout the Tumacácori unit only. Five cameras were placed in visitor use areas (i.e. trails, park access areas), and two cameras were located in more "remote" areas of the park near the Santa Cruz River (i.e. game trails and water access). The primary purpose of the Welborn and McCallum (2011, 2012) camera trap project was to collect data on user groups and develop information to be used as a decision tool for planning and administrative action (Welborn and McCallum 2011). While the project goals were more focused on park visitors and suspicious activities, the wildlife data that were collected were used in this assessment to evaluate the presence of medium- to large-sized mammals at the park.

A second camera trap monitoring project occurred in 2015 and 2016, (Perkins and Springer, unpublished data) focusing on photographing medium- to large-sized wildlife to increase species detection and relative abundance of mammals in the park. The following methods summary for the study was submitted by Nic Perkins (e-mail correspondence, 5 April 2018):

> The Inventory was conducted with three different deployments (or sets) of five cameras. The cameras were placed at points that were randomly generated using ArcGIS software. The only constraint in the creation of the random points was that no point could be within 200 meters [656 ft] of the nearest point. Cameras stayed in place for approximately six weeks before being moved. "Biotech Choice" camera placements were decided by biotech in the field and was mainly used to get photos and videos for use by the visitor center. Total effort [included] 1,205 camera nights (940 camera nights as part of the random inventory and 265 camera nights for the biotech choice).

To evaluate the condition of the presence/absence of mammals at the NHP, we compared the species recorded by Powell et al. (2005) to subsequent efforts, if available. We also used Tumacácori NHP's NPSpecies list (NPS 2018) to identify 'probable' species for the park. NPSpecies is a database that is maintained by the NPS and relies on previously published surveys, such as those included in this assessment, and expert opinion, to maintain a record of the presence or potential presence of species in national parks. The NPSpecies list also serves as a reference, especially to highlight potential data gaps of unconfirmed, but likely species expected to occur within national parks.

For the purposes of this condition assessment, mammals that were trapped using Sherman live-traps during the Powell et al. (2005) inventory, mostly ground-based rodents, were included in the small mammals category and included mice, rats and shrews. A random design was used to trap the small mammals within the park's three units. The Tumacácori unit contained 11 plots, randomly located throughout the unit. Habitat characteristics of each plot location were not included in the report. Due the small size of the Calabazas and Guevavi units, random and three subjectively placed plots were selected in each unit to maximize species detection and relative abundance. For additional details on the methods, please refer to Powell et al. (2005) report listed in the Literature Cited section of this report.

To assess the condition of medium-sized (squirrels, rabbits, small cats, foxes, and raccoons) and large-sized (big cats, ungulates, and bears) mammals, we compared camera trap survey results (and incidental observations) from Powell et al. (2005) to those from Welborn and McCallum (2011, 2012) and Perkins and Springer (unpublished data) camera trap efforts. These datasets served to compare species occurrence over a roughly 15-year period (i.e., from 2001-2002, 2011-2012, and 2015-2016). We looked for differences in the species observed during the three periods, such as whether any species were observed during one effort, especially the earlier period, but not during the later period, to evaluate current condition.

To evaluate the second measure, the mammal species present at the park were evaluated to determine nativity using the NPSpecies 'nativeness' designation (NPS 2018). If any non-native species was identified, it was evaluated for its impact(s) to native species, especially those of conservation concern.

We compared the park's list of 'present' species to the U.S. Fish and Wildlife Service's federal list of endangered and threatened species that occur in Arizona (USFWS 2015). We also reviewed species listed as greatest conservation need in Arizona (Arizona Game and Fish Department [AGFD] 2012). Under Arizona's Wildlife Action Plan, wildlife species may be listed as Tier 1A or 1B (or 1C although we do not consider those relatively lower-priority species here). Federally listed species and candidate species, as well as those for which a signed conservation agreement exists, or those that require monitoring after delisting, are included in the Tier 1A category and are considered to be of highest conservation priority (AGFD 2012).

Reference Conditions

Reference conditions for the three measures are shown in Table 53 and are described for resources in good, moderate concern, and significant concern conditions.

Condition and Trend

Table 54 lists the 18 small mammal species that were captured at the park during the Powell et al. (2005) inventory. It is also the only dataset available for evaluating the presence of small mammals at the park. Based on the baseline survey effort, detection of small mammal species was believed to be >90% of all species expected to be present at the park (Powell et al. 2005). Unfortunately, without an additional survey to compare the park's presence/absence of small mammals, the current condition is unknown with an unknown trend. However, a brief summary of information collected during the Powell et al. (2005) inventory is described below.

The small mammal species diversity found in the semi-desert grassland community at Tumacácori's NHP's Calabazas and Guevavi units is consistent with known patterns in southeast Arizona (Powell et al. 2005). The most abundant small mammal species observed throughout the park was the Sonoran desert pocket mouse (*Chaetodipus penicillatus*) with 56 captures at

Table 53. Reference conditions used to assess mammals.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Species Occurrence	Presence/Absence	All or nearly all of the species recorded during early surveys/ observations in the park were recorded during later surveys.	Several species recorded during early surveys were not recorded during later surveys (particularly if the species had previously been considered common at the park).	A substantial number of species recorded during early surveys were not recorded during later surveys (particularly if the species had previously been considered common at the park).
	Species Nativity	Non-native species are absent.	Non-native species are present but are limited by habitat type and/or do not outcompete or negatively impact native species.	Non-native species are widespread, indicating available habitat, and/or outcompete or negatively impact native species.
	Species of Conservation Concern	A moderate to substantial number of species of conservation concern occur in the park, which indicates that the NPS unit provides important habitat for these species and contributes to their conservation.	A low number of species of conservation concern occur in the park.	No species identified as species of conservation concern occur in the park.

Table 54. Small mammal species recorded at Tumacácori NHP.

Common Name	Scientific Name
Arizona cotton rat	*Sigmodon arizonae*
Bailey's pocket mouse	*Chaetodipus baileyi*
Botta's pocket gopher	*Thomomys bottae*
Brush mouse	*Peromyscus boylii*
Cactus mouse	*Peromyscus eremicus*
Deer mouse	*Peromyscus maniculatus*
Desert shrew	*Notiosorex* sp.
Fulvous harvest mouse	*Reithrodontomys fulvescens*
House mouse*	*Mus musculus*
Northern grasshopper mouse	*Onychomys leucogaster*
Northern pygmy mouse	*Baiomys taylori*
Sonoran Desert pocket mouse	*Chaetodipus penicillatus*
Southern grasshopper mouse	*Onychomys torridus*
Tawny-bellied cotton rat	*Sigmodon fulviventer*
Western harvest mouse	*Reithrodontomys megalotis*
Western white-throated woodrat	*Neotoma albigula*
White-footed mouse	*Peromyscus leucopis*
Yellow-nosed cotton rat	*Sigmodon ochrognathus*

* Non-native species.

Note: An unknown desert shrew (*Notiosorex* sp.) was captured during the Powell et al. (2005) effort and one unidentified rodent species was photographed during the Welborn and McCallum (2012) camera trap effort.

Source: Powell et al. (2005).

Calabazas, 41 captures at Guevavi, and 47 captures at Tumacácori. The cactus mouse (*Peromyscus eremicus*) was the next most abundant species with 17 captures at Calabazas, 8 captures at Guevavi, and 76 captures at Tumacácori.

Out of five SODN parks, which included Casa Grande Ruins National Monument (NM), Gila Cliff Dwellings NM, Saguaro National Park (NP), Tonto NM, and Tumacácori NHP, that participated in the vertebrate and non-vascular plant inventory, Tumacácori's Calabazas unit contained the highest small mammal species richness (Powell et al. 2002). Additionally, in relation to the other SODN parks, the Tumacácori unit had the highest number of trap nights, resulting in 1,715 survey hours (Powell et al. 2005).

A total of 20 medium- to large-sized mammals have been observed at the park (Table 55). An additional two species, eastern spotted skunk (*Spilogale putorius*) and kit fox (*Vulpes macrotis*), are listed as 'present' in the park's NPSpecies (2018) database but were not observed during any of the surveys.

The highest number of species, 16 of the 20 observed, (80%), was recorded during the Powell et al. (2005) effort, although the *Sylvilagus* sp. captured could not be identified to species level. Welborn and McCallum (2012) photographed nine to 10 species (45-50%), with the inability to identify whether the mule or white-tailed deer (or both) were present. Also, five squirrels were photographed during the Welborn and McCallum (2012) study, but individual species could not be confirmed. During the most recent camera trap study, Perkins and Springer confirmed 13 species (65%).

Four to five species (20-25%) have been observed during all survey efforts, including bobcat (*Lynx rufus*), collared peccary (*Pecari tajacu*), coyote (*Canis latrans*), and possibly the mule (*Odocoileus hemionus)* and/or white-tailed deer, depending on whether both were present during the Welborn and McCallum (2011, 2012) study. Nine species (45%), two of which are non-native, have been recorded during two of the surveys. The remaining six species (30%), two of which are non-native, were recorded during only one survey. These six included the black bear (*Ursus americanus)*, western spotted skunk (*Spilogale gracilis)*, white-backed hog-nosed skunk (*Conepatus mesoleucus)*, domestic cat (*Felis catus)* (all recorded during the Powell et al. (2005) effort only); the domestic horse (*Equus ferus caballus)* recorded during the Welborn and McCallum (2012) effort; and the mountain lion (*Puma concolor*), which was recorded most recently during the Perkins and Springer camera trap study.

Of the four native species observed during one survey only, the black bear was confirmed by identifying definitive tracks adjacent to the Santa Cruz River. In addition to the western spotted and white-backed hog-nosed skunk, two additional skunks, the striped and hooded have been documented at the park, representing all four species that are known to occur in Arizona (Powell et al. 2005). While the mountain lion was only most recently photographed, Powell et al. (2005) stated that a neighboring landowner to the park reported shooting a mountain lion on his property in 2000 (pers. comm. to Brian Powell), but none were ever photodocumented during that inventory effort at the park.

Table 55. Medium and large mammal species recorded at Tumacácori NHP.

Common Name	Scientific Name	Powell et al. (2005)	Welborn and McCallum (2011, 2012)	Perkins and Springer (unpub. data)	NPSpecies Occurrence (NPS 2018)
American black bear	*Ursus americanus*	X	–	–	Present
Bobcat	*Lynx rufus*	X	X	X	Present
Collared peccary (javelina)	*Pecari tajacu*	X	X	X	Present
Common gray fox	*Urocyon cinereoargenteus*	–	X	X	–
Coyote	*Canis latrans*	X	X	X	Present
Desert cottontail	*Sylvilagus audubonii*	– [2]	–	X	–
Domestic cat[1]	*Felis catus*	X	–	–	Present
Domestic cow[1]	*Bos taurus*	X	X	–	Present
Domestic dog[1]	*Canis familiaris*	X	X	–	Present
Domestic horse[1]	*Equus ferus caballus*	–	X	–	–
Eastern spotted skunk	*Spilogale putorius*	–	–	–	Present
Hooded skunk	*Mephitis macroura*	X	–	X	Present
Kit fox	*Vulpes macrotis*	–	–	–	Present
Mountain lion	*Puma concolor*	–	–	X	–
Mule deer	*Odocoileus hemionus*	X	X[3]	X	Present
Northern raccoon	*Procyon lotor*	X	–	X	Present
Rock squirrel	*Spermophilus variegatus*	–	– [4]	X	–
Striped skunk	*Mephitis mephitis*	X	–	X	Present
Virginia opossum	*Didelphis virginiana californica*	X	–	X	Present
Western spotted skunk	*Spilogale gracilis*	X	–	–	–
White-backed hog-nosed skunk	*Conepatus mesoleucus*	X	–	–	Present
White-tailed deer	*Odocoileus virginianus*	X	X[3]	X	Present

[1] Non-native species.

[2] Unknown *Sylvilagus* species was captured.

[3] The photographs could not be differentiated between the mule and/or white-tailed deer.

[4] Five squirrels were photographed during the Welborn and McCallum (2012) camera trap effort but were not identified to species level.

Note: X = species present.

It's expected that the inventory conducted by Powell et al. (2005) would document the highest number of species at the park given the thoroughness of effort. However, the Welborn and McCallum (2011, 2012) and Perkins and Springer efforts have documented several additional species (i.e., mountain lion, common gray fox (*Urocyon cinereoargenteus*), and rock squirrel (*Spermophilus variegatus*) since the Powell et al. (2005) survey, which is now 17-18 years old.

Data collected from the infrared cameras during the Powell et al. (2005) inventory revealed that the Virginia opossum (*Didelphis virginiana californica*) was the highest detected species, representing 37% (n=26) of all species photographed. The next highest species photographed was the collared peccary (*Pecari tajacu*) at 20% (n=14) (Powell et al. 2005).

During the Welborn and McCallum camera monitoring effort, cattle were the most observed "wildlife" with 89% (n=109) of the photos taken in the first year (Welborn and McCallum 2011), with a relative reduction in the second year at 79% (n=147) (Welborn and McCallum 2012). Of the other wildlife photographed in 2011, deer was the second most abundant, with nine photos. In 2012, native species richness increased from five species to 11 (Welborn and McCallum 2012).

The species most notably absent from the most recent camera trap efforts include the black bear and western and white-backed hog-nosed skunks, which is a similar pattern that has occurred at Saguaro NP. In fact, with the increasing development surrounding Saguaro NP's Tucson Mountain District, wildlife corridors are rapidly decreasing and believed to be likely negatively impacting species' survivability, (Swann and Perkins 2013).

In conclusion, with over 81% of the native medium- to large-sized mammal species having been photodocumented during the most recent (2015-2016) camera trap study at the park, we consider the overall condition to be good, with an unknown trend and medium confidence. Additional monitoring focusing on the medium-sized mammals, such as skunks, may be warranted, especially given the similar presence/absence pattern that is occurring at Saguaro NP.

The house mouse (*Mus musculus*) was the only non-native small mammal documented at the park. It occurred primarily at the Tumacácori unit, not far from buildings, and is only of concern relative to occupying buildings. Four non-native medium- to large-sized mammals were observed, representing 20% of all medium to large species at the park. These included the domestic cat (*Felis catus*), dog (*Canis familiaris*), cow (*Bos taurus*), and horse (*Equus ferus caballus*), all of which were recorded either during the Powell et al. (2005) and/or Welborn and McCallum (2012) studies.

The presence of bobcat at Tumacácori NHP was confirmed during all mammal surveys. Photo Credit: © R. Shantz.

While it's likely that the non-native mammals have not established populations in the park (except for possibly the house mouse), their presence may influence local biodiversity through overgrazing native vegetation, trampling soils in riparian areas creating erosion, spreading invasive species, and killing native species (e.g., feral cats killing native birds or small mammals). Throughout the U.S., free-ranging domestic cats may be responsible for as many as one billion bird deaths each year (Wildlife Society 2011, Loss et al. 2013). In general, non-native species may become more predominant as development in proximity to the park's boundaries increases.

While cattle are part of the park's historic landscape, they are prohibited from the riparian corridor within the Tumacácori unit. Cattle are destructive to vegetation and the wildlife that rely upon the vegetation structure through habitat modification and competition for resources (Powell et al. 1995). Cattle negatively impact the natural resources of the park by grazing, creating soil erosion along the stream banks, contributing to soil compaction, polluting water sources, and spreading non-native plants (Powell et al. 2005). As a persistent problem, the park has taken measures to restrict and monitor such trespassing, through the installments of fencing and camera monitoring. During the monsoon season and other flooding events, fences are either removed to save property, or destroyed, reducing the effectiveness against cattle. During the two years of the Welborn and McCallum (2011, 2012) camera monitoring at the park, 13% (2011) and 20% (2012) of the photographs were of cattle trespass.

Several times during the 2010-2013 period, the fences restricting cattle were purposely cut, in addition to being destroyed by floods. The vandalism of the fence was not necessarily to allow for cattle grazing in the park, but may have been related to horseback riders wanting access to the park (Jason Welborn pers. comm. with K. Raymond, Hydrologist with NPS Southern Arizona Office). In January 2012, K. Raymond witnessed a small herd of goats being grazed on the east central side of the park, which was eventually moved outside the park's boundary (pers. comm., dated 21 February 2019, review comment in draft assessment).

Given the fact that the non-native medium- to large-sized mammal species that are present have negatively impacted some of the park's habitat (especially riparian), which many native species (both animals and plants) depend on for their survival needs, we consider the presence of non-native species to be of moderate concern. However, the current trend is unknown and the confidence level is medium since the last photos taken were during the 2011 and 2012 camera trap surveys.

The Species of Greatest Conservation Need identified in the Arizona State Wildlife Action Plan (AGFD 2012) lists five species of small mammals and one medium-sized mammal that have been observed at the park as Tier 1C species. These are species "for which insufficient information is available to fully assess the vulnerabilities and therefore need to be watched for signs of stress" (AGFD 2012). These include the Arizona cotton rat (*Sigmodon arizonae*), fulvous harvest mouse (*Reithrodontomys fulvescens*), northern and southern grasshopper mice (*Onychomys leucogaster, O. torridus*), tawny-bellied cotton rat (*Sigmodon fulviventer*), and western spotted skunk. Based on Powell et al. (2005) inventory results, the park provides important habitat for these species and likely can contribute to their conservation, now and in the future. We consider this measure to be in good condition with an unknown trend and a medium confidence level.

An additional medium-sized mammal, kit fox (*Vulpes macrotis*), listed as a Tier 1B species by AGFD (2012), is on the park's NPSpecies (2018) list but has yet to be confirmed through photodocumentation. While the modeled habitat for the kit fox surrounds the Tumacácori unit, it doesn't actually include the park proper (AGFD 2015) but may serve as a protected area for which it can periodically pass through.

Overall Condition, Threats, and Data Gaps

To assess the condition of mammals at Tumacácori NHP, we used one indicator with three measures, which are summarized in Table 56. Small mammal species presence/absence at the park is unknown, but represents one of the most diverse NPS sites based on the regional baseline inventory results. Any additional confirmations of small mammals are believed to be of those that are uncommon or rare (Powell at al. 2005).

Medium-to large-sized mammals species presence/absence at the park is in good condition, although trespass cattle is of concern. The park also supports a high number of species that are listed in Arizona's State Wildlife Action Plan (AGFD 2012) as Species of Greatest Conservation Need. As a result, the overall condition rating for mammals is unknown to good, with an unknown trend.

Most native mammals are susceptible to human development, harassment, habitat loss, poor water quality, and human-influenced mortality. Medium- to large-sized mammals are more prone to stressors related to an accumulation of human activity because their home ranges most likely surpass the park where ideal habitat could be limited. Due to the limited distance of small mammals' home ranges, which most likely confines this group of mammals, park staff has greater control of eliminating stressors that reside within the park's boundaries.

Human activity, in and around the park, is a stressor for wildlife. Due to the highly desirable real estate of the Santa Cruz River Valley, there is concern about increases in residential developments along the park's boundaries and throughout the greater area that could affect the biodiversity associated with the river habitat (Powell et al. 2005). Increased development and settlement of humans can increase non-native plant presence and extent, toxin runoff, sediment displacement, wildlife corridor displacement, habitat loss and fragmentation, and harassment and mortality from domesticated animals (Powell et al 2005). Additionally, the degradation of the riparian area due to drought and uncertain streamflow from the Nogales International Wastewater Treatment threatens very important habitat for wildlife.

In 2004, a group of concerned land managers and biologists from federal, state, and regional agencies, along with researchers from Northern Arizona University, formed the Arizona Wildlife Linkages Workgroup (AWLW). The workgroup identified critical areas that would help preserve Arizona's diverse natural resources in the midst of the state's rapid population growth. They identified and mapped large areas of protected habitat (i.e., habitat blocks) and the potential linkages (i.e., matrix) between these protected areas. This effort became known as the *Arizona Missing Linkage*s project, identifying 152 statewide coarse-level linkage zones (AWLW 2006). The Tumacacori-Santa Rita Linkage (TSRL) was one of the first priority areas identified for further evaluation (AWLW 2006).

Table 56. Summary of mammal indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Presence/ Absence	Small Mammals (unknown condition, dashed circle)	The current condition of small mammals presence/absence is unknown because only one inventory has been conducted at the park. Without a follow-up survey, comparison of species presence/absence cannot be made. No information on trend is available, and our confidence level is low.
		Medium to Large Mammals (green circle)	The current condition of medium- to large-sized mammals presence/absence is good, with an unknown trend and medium confidence. The most recent camera-trap study has documented over 81% of the expected native species, although the western and white-backed hog-nosed skunks have not been observed since the 2001-2002 baseline inventory, which is now 17-18 years old and may warrant focused monitoring efforts.
	Species Nativity	(yellow circle)	A total of five non-native mammals have been documented at the park. And while the one small mammal species present is not of concern, the medium (e.g., cat) and large (e.g., cow) mammals have impacted resources at the park, specifically from cattle trespass. As a result, we consider this measure to be of moderate concern with an unknown trend and medium confidence in the current condition rating.
	Species of Conservation Concern	(green circle)	Six species are listed by AGFD (2012) as species of conservation need. While these six are of the lowest concern, it demonstrates that the park provides habitat and refugia for species of conservation need. The condition for this measure is good with medium confidence and an unknown trend.
Overall Condition	Summary of All Measures	(dashed circle); (green circle)	While we don't have data to compare the presence/absence of small mammals over time (resulting in an unknown condition), over 81% of the native medium-large-sized mammals have been photodocumented during the most recent camera-trap study, warranting good condition. Unfortunately, some of the non-native species are impacting vegetation resources but park staff continue to maintain fencing to mitigate further impacts. The national park provides a protected area that has exhibited one of the most diverse small mammal communities as compared to other Sonoran Desert parks in the southwest.

The TSRL study identified four terrestrial and one riparian corridor along the Santa Cruz River as biologically important to the sustainability of regional wildlife moving between the Santa Rita and Tumacacori Mountains (Beier et al. 2006). The second northernmost corridor included the park and more than 5 km (3.1 mi) of the Santa Cruz River, providing potential pass-through and live-in habitat for Coues' white-tailed deer (*Odocoileus virginianus couesi*), porcupine (*Erethizon dorsatum*), and coati (*Nasua narica*), along with several additional species including amphibians and reptiles (Beier et al. 2006). The Santa Cruz River represented the riparian corridor linkage and is the only perennial water source throughout the entire TSRL (Beier et al. 2006).

Identifying and protecting high quality habitat is critical for continuing to protect species survival needs, but it's important to note that within the last 100 years, three species that have likely occurred at Tumacácori NHP have been extirpated from the park. These species are grizzly bear (*Ursus arctos*), Mexican gray wolf (*Canis lupus baileyi*), and bighorn sheep (*Ovis canadensis*).

In 1998, the AGFD (2019), along with other cooperating agencies, released 11 captive-reared wolves into the Blue Range Wolf Recovery Area in eastern Arizona as an attempt to recover the species in a portion of its former population area. Subsequent releases have occurred since then. While no wolves have been recently documented in Tumacácori NHP, their historical range does in fact include the park (Heffelfinger et al. 2017). An additional extirpated species, the federally endangered jaguar (*Panthera onca*), is the only species that has been seen recently in proximity to the park. In recent years, it has been sighted (and confirmed) in the Santa Rita Mountains on U.S. Forest Service land, located east of the Tumacácori NHP (Wildlife Conservation Society 2019). It too is a species that may be increasing due to recovery efforts throughout the region.

With continued camera trap monitoring for medium- and larger-sized mammals and an excellent baseline inventory of small mammals, periodic sampling of "indicator" species within each habitat type may assist park managers and scientists develop status and trends of the mammal community at and around the park over time. Unfortunately, small mammals can also be a nuisance to the cultural resources at the park by burrowing in the ground impacting archeological resources and the mission building foundations (NPS 2014a). However, having one of the richest small mammal communities within SODN parks is impressive, especially given the small size of Tumacácori NHP.

Sources of Expertise

Anna Mateljak (formerly Iwaki), Biological Science Technician, formerly with NPS Sonoran Desert Inventory and Monitoring Network co-authored this assessment with Kim Struthers, NRCA Coordinator and Science Writer/Editor with Utah State University.

Herpetofauna

Background and Importance

The Upper Santa Cruz River sustains one of the most ecologically diverse riparian areas in the American Southwest (King et al. 1999), supporting human communities for over 3,500 years (Sutherland 2009). Tumacácori National Historical Park (NHP) was established for three mission sites built in the 1600s, and all three units reside along the Upper Santa Cruz River.

The Sonoran semi-desert grassland and riparian ecosystems of the NHP create a corridor for biological flora and fauna to and from Mexico, located 29 km (18 mi) south of the park. The health, distribution, and diversity of herpetofauna, which includes amphibians and reptiles, found along the Santa Cruz River is important to the park and the surrounding watershed because they are one of the best terrestrial vertebrate indicators of riparian ecosystem health (Lowe 1989). Humans and other biological organisms have a great need for water in desert environments, which emphasizes the protection of the park's aquatic and riparian ecosystems and associated wildlife.

Herpetofauna constitute an important part of the food web. They serve as prey for many animals, including mammals, birds, and other herpetofauna. As predators, they are beneficial for pest control too in that they consume insects and other invertebrates, and species traditionally considered to be pests to the agriculture industry, such as mice, rats, squirrels, starlings, and more. They are also important trophic links and facilitators of energy flow. Amphibians, in particular, are indicators of wetland ecosystem health. They are sensitive to a variety of threats due to their permeable skin and complex life histories, thus, can serve as early indicators of ecosystem change when monitored over time.

Data and Methods

To assess the condition of the herpetofauna at Tumacácori NHP, we used one indicator of condition, species occurrence, with a total of three measures: species presence/absence, species nativity, and species of conservation concern.

The only herpetofauna inventory or study conducted at Tumacácori NHP was completed in 2001 and 2002 by the U.S. Geological Survey (USGS) during the park's vascular plant and vertebrate baseline inventory (Powell et al. 2005). Using repeatable study designs and standardized field techniques, four methods representing plot-based and flexible non-plot based techniques were used for detecting rare and elusive amphibian and reptile species (Powell et al. 2005). Intensive surveys used standardized time and area

Coachwhip in a tree at Tumacácori NHP. Photo Credit: NPS.

constraints that were located in each dominant vegetation community found in the park. Species abundance and richness by community types were analyzed based on the data from the intensive surveys. To maximize species richness and detection, extensive surveys were implemented and not limited to random sites, time, and area. To inventory nocturnal/crepuscular species, data were collected through extensive survey methods (Powell et al 2005). Each unit at the park was surveyed for species richness and abundance separately then combined and evaluated as one park unit.

Due to the park's small size, the herpetofauna surveys occurred in categorized habitat zones to include the most species diversity. Intensive surveys occurred in 1) semi-desert grassland, 2) agricultural, 3) mesquite bosque, 4) cleared bosque, and 5) riparian community types. The Calabazas and Guevavi units reflect only semi-desert grassland, while the Tumacacori unit reflects the remaining community types.

To evaluate the species presence/absence measure, we needed more than one survey effort to compare/contrast recorded species, providing a crude comparison of persistence over time. Unfortunately, as of 2018, only one herpetofauna survey has been conducted at the park. So instead, we discuss the species recorded by Powell et al. (2005) in addition to species that may occur at Tumacácori NHP based on regional surveys along the Santa Cruz. We also include the park's NPSpecies list of herpetofauna (NPS 2018), primarily for reference purposes, especially to highlight potential data gaps of species considered present but not observed during the baseline inventory.

To evaluate the second measure, the herpetofauna species recorded during all survey or research efforts at the park, or not recorded during the surveys but listed as present in the park's NPSpecies list (NPS 2018), were evaluated to determine nativity. If a non-native species was present, it was evaluated for its impact(s) to native species, especially those native species of conservation concern.

For the third measure, we compared the park's list of 'present' species to the U.S. Fish and Wildlife Service's federal list of endangered and threatened species that occur in Arizona (USFWS 2015). We also reviewed species listed as greatest conservation need in Arizona (Arizona Game and Fish Department [AGFD] 2012). Under Arizona's Wildlife Action Plan, wildlife species may be listed as Tier 1A or 1B (or 1C although we do not consider those relatively lower-priority species here). Federally listed species and candidate species, as well as those for which a signed conservation agreement exists, or those that require monitoring after delisting, are included in the Tier 1A category and are considered to be of highest conservation priority (AGFD 2012).

Reference Conditions

Reference conditions used to evaluate the three measures of herpetofauna occurrence are presented in Table 57 and described for resources in good, moderate concern, and significant concern conditions.

Condition and Trend

With no natural resource management emphasis until 2010 at Tumacácori NHP, monitoring and recording of natural resources was limited to incidental observations, sporadic specimen collections, and local

Table 57. Reference conditions used to assess herpetofauna.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Species Occurrence	Presence/Absence	All or nearly all of the species recorded during early surveys/observations in the park were recorded during later surveys.	Several species recorded during early surveys were not recorded during later surveys, particularly if the species had previously been considered common at the park.	A substantial number of species recorded during early surveys were not recorded during later surveys, particularly if the species had previously been considered common at the park.
	Species Nativity	Non-native species are absent.	Non-native species are present but are limited by habitat type and/or do not outcompete native species for resources.	Non-native species are widespread and outcompete native species for resources.
	Species of Conservation Concern	No reference conditions were developed.	No reference conditions were developed.	No reference conditions were developed.

studies outside the park. In 1940, J.Y. Beaty from the Chicago Academy of Science, collected a Clark's spiny lizard (*Sceloporus clarkii*) specimen from the park. In 1962, a gopher snake (*Pituphis catenifer*) was collected by R.L. Bezy from the University of Arizona (Powell et al. 2005). However, the majority of Tumacácori NHP's herpetofauna species confirmations occurred during its 2001-2002 baseline inventory. During that effort, Powell et al. (2005) recorded seven amphibian and 17 reptiles species for a total of 24 species (Table 58). The number observed at the Calabazas unit was 11 species. The number of species observed at the Guevavi unit was nine and 22 were observed at the Tumacacori unit (Powell et al. 2005). The NHP's NPSpecies list (NPS 2018) includes an additional six reptile species listed as 'present' at the park but no additional amphibians are listed as present other than what was observed during the Powell et al. (2005) effort.

Table 58. Amphibian and reptile species list for Tumacácori NHP.

Group	Common Name	Scientific Name	Powell et al. (2005)	NPSpecies Occurrence (NPS 2018)
Amphibians	American bullfrog[1]	*Lithobates catesbeianus*	X	Present
	Couch's spadefoot	*Scaphiopus couchii*	X	Present
	Great Plains toad	*Anaxyrus cognatus*	X	Present
	Mexican spadefoot	*Spea multiplicata*	X	Present
	Sonoran desert toad	*Incilius alvarius*	X	Present
	Western narrow-mouthed toad	*Gastrophryne olivacea*	X	Present
	Woodhouse's toad	*Anaxyrus woodhousii*	X	Present
Lizards	Clark's spiny lizard	*Sceloporus clarkii*	X	Present
	Coachwhip	*Coluber flagellum*[2]	X	Present
	Common lesser earless lizard	*Holbrookia maculata*	X	Present
	Common side-blotched lizard	*Uta stansburiana*	–	Present
	Desert grassland whiptail	*Aspidoscelis uniparens*	X	Present
	Desert spiny lizard	*Sceloporus magister*	–	Present
	Eastern fence lizard	*Sceloporus undulatus*	X	Present
	Gila spotted whiptail	*Aspidoscelis flagellicauda*	–	Present
	Ornate tree lizard	*Urosaurus ornatus*	X	Present
	Regal horned lizard	*Phrynosoma (Anota) solare*	X	Present
	Sonoran spotted whiptail	*Aspidoscelis sonorae*[2]	X	Present
	Tiger whiptail	*Aspidoscelis tigris*[2]	–	Present
Snakes	Gopher snake	*Pituophis catenifer*	X	Present
	Long-nosed snake	*Rhinocheilus lecontei*	X	Present
	Smith's black-headed snake	*Tantilla hobartsmithi*	X	Present
	Sonora mud turtle	*Kinosternon sonoriense*	X	Present
	Sonoran coralsnake	*Micruroides euryxanthus*	X	Present
	Sonoran nightsnake	*Hypsiglena chlorophaea*[2]	X	Present
	Sonoran whipsnake	*Coluber bilineatus*	–	Present
	Western diamond-backed rattlesnake	*Crotalus atrox*	X	Present
	Western patch-nosed snake	*Salvadora hexalepis*	X	Present
Turtle	Ornate box turtle	*Terrapene ornata*	X	Present
Tortiose	Mojave desert tortiose	*Gopherus agassizii*	–	Present
Total Number			24	30

[1] Non-native species.

[2] Following the Society for the Study of Amphibians and Reptile (SSAR 2017), the scientific name for species was subdivided into several subspecies after observation was made.

Note: X = species present.

In the Tumacácori unit, most of the species were confirmed through extensive surveys (n=20), but species were also confirmed through intensive surveys (n=7), and incidental observations (n=1). Calabazas unit had species confirmed through the use of all three methods: intensive (n=4), extensive (n=7), and incidental observations (n=3). The Guevavi unit species confirmation also occurred through intensive surveys (n=6), extensive (n=7), and incidental observations (n=2).

During intensive surveys, five community types were sampled to calculate species richness and abundance. The community types included semi-desert grassland, agriculture, mesquite bosque, cleared bosque and riparian. Species richness was highest in the semi-desert grassland and riparian communities, with six species each. The mesquite bosque community type reflected the lowest number of species, with only two observed. However, despite the fact that the riparian and semi-desert grassland had the same number of species, the riparian community had 185 detections compared to 39 detections in the semi-desert grassland, representing 30% higher detections than any other community type in the park (Powell et al. 2005).

The most abundant species observed throughout the park was the Sonoran spotted whiptail (*Aspidoscelis sonorae*) with 242 extensive survey records and 125 intensive survey records. The most abundant species found in the semi-desert grassland community type were the common lesser earless lizard (*Holbrookia maculata*), the Clark's spiny lizard, and the regal horned lizard (*Phrynosoma solare*). The most abundant species observed in the riparian community were the eastern fence lizard (*Sceloporus undulatus*) and whiptails. Clark's spiny lizard was the most widespread species, confirmed in both intensive and extensive surveys and in all habitats throughout all three park units. It's also the species that was vouchered in 1940 by Beaty as previously mentioned.

Powell et al. (2005) graphed the cumulative number of species recorded based on number of surveys to determine species accumulation curves for each park unit. Based on the curves, they believe they observed the majority of species that would have been present at the park during the 2001-2002 environmental conditions, which were dry given the lack of precipitation during both years. Powell et al. (2005) included an appendix in their report listing species that were not recorded during their baseline inventory, but may occur in the park based on documentation in the Santa Cruz River region by other researchers or published range maps (Stebbins 2003, Rosen and Mauz 2001, Rosen (pers. comm.), Arnold 1940, Drost 1998, Rosen et al. 2004, or reliable park of volunteer personnel sightings, all as cited by Powell et al. 2005). This list included an additional 47 species, although some of which are locally extirpated (see species of conservation concern discussion). The majority of species on the list are reptiles, indicating a data gap in terms of presence and available habitat for this group at the park.

The canyon treefrog (*Hyla arenicolor*), red-spotted toad (*Anaxyrus punctatus*), and Sonoran green toad (*Anaxyrus retiformis*) have been observed along the Santa Cruz River but not within the park. Powell et al. (2005) states that "the few records of the canyon treefrog in the Tumacácori NHP area of the Santa Cruz River suggest that the species may not regularly occur in this area, and to our knowledge the red-spotted toad has not been reported in this area within the last ten years." There have been reliable reports of ring-necked snakes (*Diadophis punctatus*) and common kingsnakes (*Lampropeltis getula*) at the park and black-necked (*Thamnophis cyrtopsis*) and checkered garter snakes (*T. marcianus*) between the Tumacácori and Calabazas units. Historic records and nearby studies suggest several reptiles "might pass through the park in the course of movement from nearby areas .....but are uncommonly seen (e.g., fossorial species that are active on the soil surface for only a small percentage of their lifetimes [Ivanyi et al. 2000 as cited by Powell et al. 2005]) and some may be extirpated."

While no additional herpetological work has been conducted at the park since the Powell et al. (2005) baseline inventory, Tumacácori NHP participates in the Sonoran Institute's annual report, *A Living River: Charting The Health Of The Upper Santa Cruz River* (SI 2018), submitting data on monitored resources to contribute to the greater ecological system of the Santa Cruz River (Sutherland 2009, Spillane 2010, 2011, Sonoran Institute WYs 2008-2014).

Amphibians have most likely reached a species richness threshold based on habitat degradation, regional population declines, known ranges of amphibians, and local extirpations (Powell et al. 2005). If the park can correlate a herpetofaunal indicator species with a closely monitored resource, such as water, managers will have a better understanding of the condition of the herpetofauna and changes over time. While reptile documentation at Tumacácori NHP is only partially complete, more surveys or studies will help inform current condition of presence/absence for this group. Without data to compare and contrast species presence/absence over time, condition and trend are unknown.

Only one non-native species, American bullfrog (*Lithobates catesbeianus*), was observed during the Powell et al. (2005) survey effort. Unfortunately, it was the fifth most frequently observed species (n=23) but only in the Tumacácori unit (Powell et al. 2005). The decline, and in some cases extirpation, of native fishes, amphibians, and some aquatic reptiles in the southwestern U.S., has been attributed to a variety of factors, including the introduction of the American bullfrog, which is "voracious predator." As such, Powell et al. (2005) cited the American bullfrog as a management concern at Tumacácori NHP. Unfortunately, without follow-up surveys, we do not know the population status of the bullfrog and its impact to the native species present at the NHP, thus condition and trend are unknown for the species nativity measure.

Of the herpetofauna species that were observed by Powell et al. (2005) or are considered present at Tumacácori NHP (NPS 2018), a total of eight (one amphibian and seven reptiles) are identified as species of greatest conservation need (SGCN) in Arizona (Table 59). Two species, Mojave desert tortiose (*Gopherus agassizii*) and ornate box turtle (*Terrapene ornata*), are the highest priority species (Tier 1A). In addition to those eight species, three amphibians, lowland (*Lithobates yavapaiensis*) and Chiricahua leopard frogs (*L. chiricahuensis*) and the Tarahumara (*L tarahumarae*) frog have been locally extirpated from the park and surrounding area (Powell et al. 2005).

No reference conditions were developed for this measure since it's largely descriptive of the species presence/absence measure, therefore, no condition rating was assigned.

Overall Condition, Threats, and Data Gaps

To assess the condition of herpetofauna at the park, we used one indicator with three measures, (Table 60). Since the initial herpetofauna inventory was completed at Tumacácori NHP, new species documented have been minimal. Unfortunately, without follow-up surveys to the park's comprehensive baseline inventory, which was conducted 16-17 years ago, we cannot assign a condition or trend rating, thus the overall condition and associated trend of herpetofauna is unknown.

Herpetofauna species are susceptible to changes in water resources, habitat loss and fragmentation, introduction of exotic species, pollution, roadkill, and disease (Malone 1999). Summer monsoons cause increased runoff of toxins and sediment from adjacent lands used for pasture, agriculture, and dense housing developments into the Santa Cruz River. Trespassing cattle and other domesticated animals increase exotic species transportation, wildlife harassment, soil disruption and habitat fragmentation (Powell et al. 2005). In recent years, undocumented immigrants and drug traffickers have increasingly used the Santa Cruz River as a corridor, which increases U.S. Border Patrol activities. This, in turn, leads to increased wildlife disturbance, trash, social trails and trampling,

Table 59. Amphibians and reptiles of conservation concern.

Group	Common Name	Scientific Name	AGFD (2012) Species of Greatest Conservation Need Tier
Amphibian	Sonoran desert toad	*Incilius alvarius*	1B
Reptiles	Gila spotted whiptail	*Aspidoscelis flagellicauda*	1B
	Mojave desert tortiose	*Gopherus agassizii*	1A
	Ornate box turtle	*Terrapene ornata*	1A
	Regal horned lizard	*Phrynosoma (Anota) solare*	1B
	Sonora mud turtle	*Kinosternon sonoriense*	1B
	Sonoran coralsnake	*Micruroides euryxanthus*	1B
	Sonoran whipsnake	*Coluber bilineatus*	1B

Note: 1A = highest priority species. 1B = next highest priority species.

Table 60. Summary of herpetofauna indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Presence/ Absence		The current condition of herpetofauna presence/absence is unknown because the last park-wide inventory of herpetofauna was conducted 16-17 years ago (2001 and 2002), and no recent surveys are available from which to compare current condition of presence/absence. No information on trend is available, and our confidence level is low.
	Species Nativity		One non-native species (American bullfrog) has been documented within the NHP. Unfortunately, without follow-up surveys, we do not know its impact to native species and its population status within the park. We do, however, know that it is thought to be a primary cause of declines of leopard frogs and gartersnakes that has occurred in Cochise County, Arizona (Rosen and Schwalbe 1995) just east of the park.
	Species of Conservation Concern	n/a	Eight species, one amphibian and seven reptiles, that are considered present at the park are listed as species of greatest conservation need in Arizona. In addition, three frogs are believed to have been extirpated from the park. The park may also contain additional reptile species that are of conservation concern but more surveys need to be conducted to determine presence. No reference conditions were developed for this measure so condition and trend are unknown.
Overall Condition	Summary of All Measures		While we don't have current data to evaluate the condition or trend for herpetofauna at the park, it is noteworthy that the protected habitat in the park supports eight species of conservation concern. Additional species, especially reptiles, may be present since data are lacking for this group. The overall condition and trend are unknown.

compromised safety for staff and visitors, and potential negative impacts to the Santa Cruz River.

Amphibians and aquatic reptiles are very sensitive to changes in water quality and quantity because of their direct dependence on aquatic habitats. The quality and quantity of the effluent from the Nogales International Wastewater Treatment Plant (NIWTP) is a stressor on the resources that directly and indirectly rely on it. Since NIWTP's 2009 system upgrade, water quality has improved dramatically (NPS 2014b, Gwilliam et al. 2016, Zugmeyer 2016), but water quantity has declined. During mid-June of 2008 to 2014, water did not flow past the Tubac Reach just north of the park during four of the seven years monitored (Zugmeyer 2016). With improved water quality, Mexico now uses approximately half of this water for agriculture and groundwater recharge (NPS 2014b) and continued flows are uncertain as Mexico retains full legal rights to the effluent discharged into the river (Brewer and Fabritz-Whitney 2012). Although reduced flows can be partially attributed to this diversion, other factors such as increased water infiltration with improved water quality and fewer scouring floods have also reduced water quantity (Zugmeyer 2016).

An early Santa Cruz River study, conducted by King et al. (1999), assessed "the potential and actual effects of [what was then] current contaminant levels from effluent on macroinvertebrates, fish, and wildlife populations" along the Santa Cruz. Their study encompassed a 46.2 km (28.7 mi) stretch of river starting from the U.S./Mexico border, encompassing Tumacácori NHP. While the researchers studied many ecological resources that may have been affected by water quality, herpetofauna was not included. From 1997 and 1998, an amphibian and aquatic reptiles-specific study was conducted along the same stretch (Drost 1998). While none of Tumacácori's units were included as study sites, the park units resided within the greater study area and between study sites. Two of Drost's sites, Palo Parado and Carmen, were located approximately 4 km (2.5 mi) south and 3.2 km (2 mi) north of Tumacácori NHP, respectively. Species totals were not provided, but each site had a significant species finding. Palo Parado had the only southern spadefoot (*Scaphiopus multiplicatus*) documented, which is now referred to by the Society for the Study of Amphibians and Reptiles (SSAR) (2017) as either western spadefoot (*Spea hammondii*) or Mexican spadefoot (*Spea multiplicata*), and Carmen had the only documented western narrow-mouthed toad (*Gastrophryne *olivacea*). Both the Mexican spadefoot and narrow-mouthed toad were observed at Tumacácori NHP by Powell et al. (2005). The results of Drost's (1998) study found that the overall amphibian diversity and species richness along the Santa Cruz River was low (Drost 1998). Although the survey occurred prior to the water quality improvements. According to the Sonoran Desert Inventory and Monitoring Network's 2015 water resources report for the park, no Arizona State water standards were exceeded for a suite of water quality measures (Gwilliam et al. 2016).

While the variety of amphibian species recorded at Tumacácori NHP during its baseline inventory is relatively complete, there aren't sufficient data to indicate that abundance levels have increased as the Santa Cruz River water quality has improved. Additionally, water quantity is influenced by climate change, and recent climate conditions in the park and elsewhere in the desert southwest have already shifted beyond the historical range of variability (HRV) (Prein et al. 2016). In Tumacácori NHP, four temperature variables were categorized as "extreme warm," which was defined as values exceeding 95% of the HRV (Monahan and Fisichelli 2014). While no precipitation variables were classified as extreme dry, evaporation and transpiration, and thus dryness, will increase as the temperature warms (Monahan and Fisichelli 2014). Reptiles have scaly skin, allowing them to survive without water, but amphibians are smooth and scaleless, and the absence of water on their skin for a prolonged period can result in death. Regardless of the reasons for reduced water quantity, it's likely that dry conditions will stress the aquatic and riparian environments that serve as habitat for the park's and regional herpetofauna species.

Further work on identifying amphibian or reptile species indicators within each habitat type could reveal herpetofauna condition for each community type. With the lack of subject-matter experts on site, to increase the park's reptile list, the collection of road kill and high quality photography of species observed is a way to effectively document new species in the future.

Sources of Expertise

Anna Mateljak (formerly Iwaki), Biological Science Technician, formerly with NPS Sonoran Desert Inventory and Monitoring Network co-authored this assessment with Kim Struthers, NRCA Coordinator and Science Writer/Editor with Utah State University.

Fish

Background and Importance

Tumacácori National Historical Park (NHP) is situated along the Santa Cruz River within the upper Santa Cruz River watershed (NPS 2014a). The headwaters of the Santa Cruz River originate in Mexico's San Rafael Valley where the river meanders 52 km (32 mi) before entering the U.S. near Nogales, Arizona (Tellman et al. 1997). The river then flows north for approximately 16 km (10 mi) before entering Tumacácori NHP. An approximately 2.3 km (1.4 mi) stretch of river flows through the park (Gwilliam et al. 2013). Historically, the upper Santa Cruz River supported several native fish species including the Gila topminnow (*Poeciliopsis occidentalis*), desert sucker (*Catostomus clarkii*), Sonora sucker (*Catostomus insignis)*, and longfin dace (*Agosia chrysogaster)* (Zugmeyer 2016). The Gila topminnow is listed as endangered by the U.S. Fish and Wildlife Service's Endangered Species Program (USFWS 2017), but all native fish in the region are considered species of concern by the Arizona Game and Fish Department (AGFD 2013).

The Santa Cruz River has a long history of development and resource extraction, including ranching, agriculture, and mining (Tellman et al. 1997). Historically, the river flowed perennially from localized precipitation and snowmelt at its headwaters (Tellman et al. 1997). Today however, water flowing in the Santa Cruz River is quasi-perennial treated effluent from the Nogales International Wastewater Treatment Plant (NIWTP) (Gwilliam et al. 2016). Prior to an upgrade to the plant in 2009, water quality was poor but has since improved substantially with beneficial consequences for native fish species (Gwilliam et al. 2016). By 2013, a new wastewater treatment plant was built in Mexico, which further improved water quality. However, some of this water is now diverted back into Mexico, effectively reducing the amount of water available for fish and other wildlife and plants (NPS 2014b).

Data and Methods

This assessment is based one indicator, species occurrence, with a single measure, presence/absence. Currently, fish are monitored through a collaborative effort between the Sonoran Institute, the Arizona Game and Fish Department, and the National Park Service (Gwilliam et al. 2016). The current monitoring site is a reach at the Santa Gertrudis Crossing referred to as the Santa Gertrudis index reach (Figure 20). Prior to these current monitoring efforts, a vascular plant and vertebrate inventory of Tumacácori NHP, which included fish surveys at two park locations, was conducted during 2001 and 2002 (Powell et al. 2005). This assessment is based on these two surveys.

A male and female Gila topminnow. Photo Credit: © Bruce D. Taubert/Arizona Game and Fish Department.

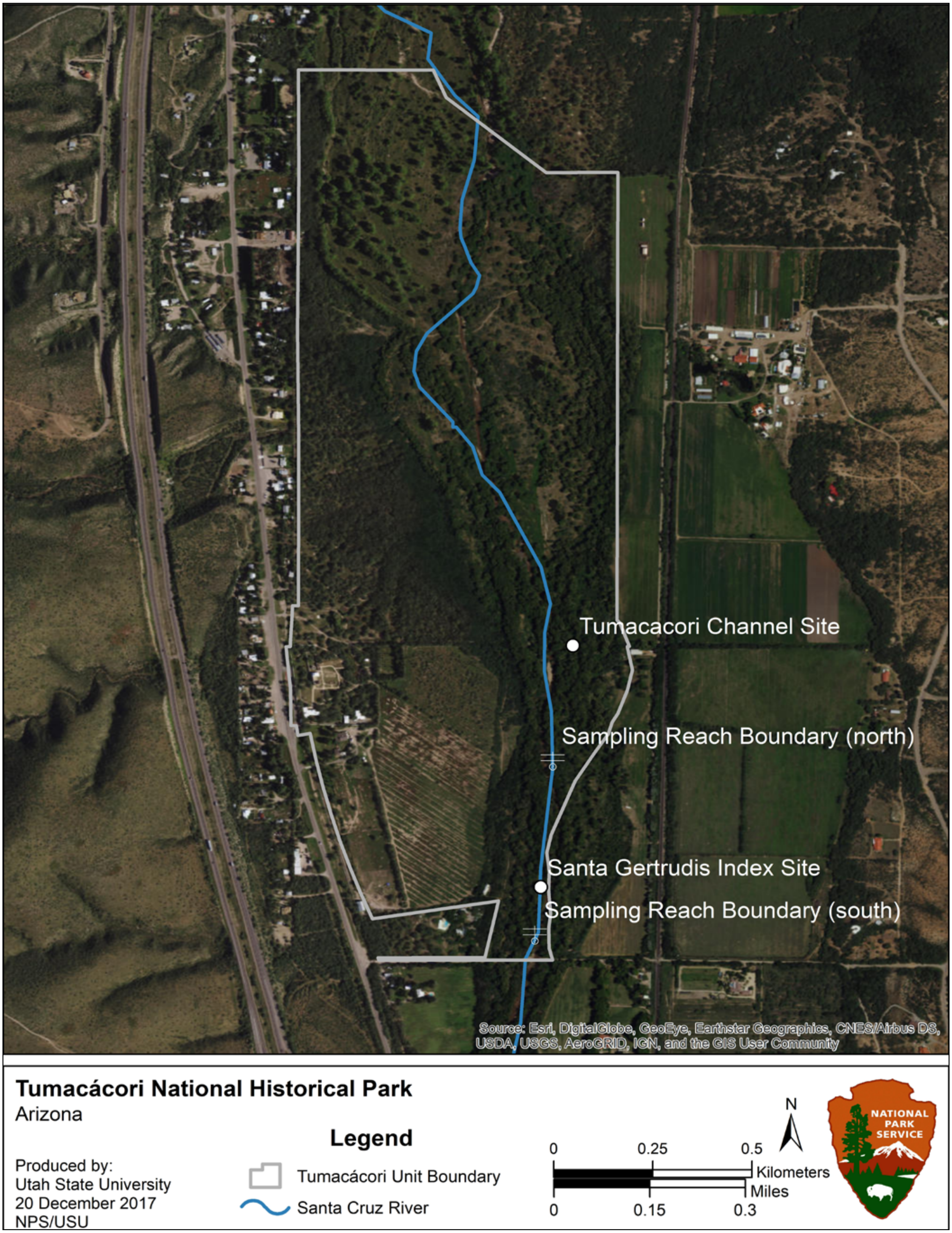


Figure 20. **Fish sampling locations in Tumacácori NHP.**

In 2001 and 2002 two sites were inventoried for fish in Tumacácori NHP's main unit as part of a vascular plant and vertebrate inventory that included eight Arizona and New Mexico national parks and monuments within the National Park Service's (NPS) Sonoran Desert Inventory and Monitoring Network (Powell et al. 2005). One site was located along the Santa Cruz River at the approximate location of the Santa Gertrudis index reach and the other site was located in the Tumacácori Channel (also sometimes referred to as Cosper Slough) (Powell et al. 2005) (Figure 20). "The channel is an abandoned meander that maintains its downstream connection with the Santa Cruz River" (Powell et al. 2005). The Santa Cruz River sampling site was located 30 m (98 ft) downstream of the confluence with the channel to approximately 25 m (82 ft) south of Santa Gertrudis Lane. Backpack electrofishing with a Smith-Root unit and dipnetting (4-mm mesh [0.2 in]) methods were used to capture fish at the two locations. Fish were sampled during spring (April and May) and fall (November) on a single day in each of the three months. We reported the total number of fish caught by species and reach.

The second survey was a multi-agency effort that began in 2009 (Gwilliam et al. 2017). We obtained data through 2017, but these surveys are part of a long-term effort. Fish were sampled at the Santa Gertrudis index reach on a single day in November from 2009 to 2017 via backpack electrofishing and seining with a 3.2-m (0.1-in) mesh net (Gwilliam et al. 2016). Data were summarized by the total fish caught per species and by Catch Per Unit Effort (CPUE) by species and method for each year. CPUE controls for effort expended and was calculated by dividing the number of fish caught by the number of minutes for electrofishing and net area (m^2) for seining. Data for 2016 and 2017 were provided by the Sonoran Institute (Sonoran Institute, C. Zugmeyer, Ecologist, e-mail message, 18 December 2017). Data for previous years were reported in Gwilliam et al. (2016).

We compared presence/absence between the two studies. However, comparing the two surveys may be complicated by slight differences in survey methods. For example, Powell et al. (2005) surveyed using electrofishing and dip nets, while Gwilliam et al. (2016) reported electrofishing and seining.

Reference Conditions

Reference conditions are described for resources in good, and moderate concern, and significant concern conditions (Table 61).

Condition and Trend

Of the 36 species of fish native to Arizona, four have been reported at Tumacácori NHP, all of which are considered species of conservation concern by Arizona Department of Game and Fish, including the federally endangered Gila topminnow (AGFD 2013, USFWS 2017). In addition, four non-native species have been reported in park waters for a total of eight fish species (Table 62). This list was based on surveys conducted by Powell et al. (2005) described below.

During the 2001 and 2002 inventory surveys, all eight species were documented between the two monitoring sites (Powell et al. 2005) (Table 63). Four were non-native and four were native, including the Gila topminnow. The non-native western mosquitofish (*Gambusia affinis*) was the most common species caught in the Tumacácori Channel while the native longfin dace was the most commonly caught species in the Santa Cruz River. Although far less numerous than longfin dace and western mosquitofish, Gila topminnow was among the most commonly caught species in both locations. All eight species were caught in the Tumacácori Channel, while only five species were caught in the Santa Cruz River (two native species and three non-native species). The native desert sucker and Sonora sucker were absent in the Santa Cruz River as was the non-native bluegill (*Lepomis macrochirus*).

During the 2009-2017 multi-agency surveys, three species were caught in the Santa Gertrudis index reach (Table 64). These were the longfin dace, Gila topminnow, and the western mosquitofish. Longfin dace were detected in all years except 2009. Gwilliam et

Table 61. Reference conditions used to assess fish in Tumacácori NHP.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Species Occurrence	Presence/ Absence	Presence/absence reflects a healthy fish community composed of native fish species and no non-native fish species .	Presence/absence reflects a moderately healthy fish community with mostly native fish species and few non-native species.	Presence/absence reflects an unhealthy fish community with few native species and mostly non-native species.

Table 62. Fish species reported for Tumacácori NHP.

Common Name	Scientific Name
Bluegill[1]	*Lepomis macrochirus*
Desert sucker	*Catostomus clarkii*
Gila topminnow[2]	*Poeciliopsis occidentalis*
Green sunfish[1]	*Lepomis cyanellus*
Largemouth bass[1]	*Micropterus salmoides*
Longfin dace	*Agosia chrysogaster*
Sonora sucker	*Catostomus insignis*
Western mosquitofish[1]	*Gambusia affinis*

[1] Non-native species.

[2] Listed as endangered by the U.S. Fish and Wildlife Service's Endangered Species Program (USFWS 2017).

Table 63. Total fish species caught in Tumacácori NHP during 2001 and 2002.

Common Name	Tumacácori Channel	Santa Cruz River
Desert sucker	6	0
Gila topminnow	172	182
Longfin dace	434	979
Sonora sucker	24	0
Bluegill	6	0
Green sunfish	1	4
Largemouth bass	3	1
Western mosquitofish	1,243	273

Source: Powell et al. (2005).

al. (2016) indicated that this species was absent during at least some years between 2003 and 2008, returning to the index reach by 2009, although not reported until 2010 (Gwilliam et al. 2016). The Gila topminnow was not detected until 2016. In 2015 the Gila topminnow was rediscovered in the upper Santa Cruz River near Mexico after a 10-year absence (Zugmeyer 2016). The return of these two native species to park waters is likely the result of higher water quality since the 2009 upgrade of the NIWTP (Gwilliam et al. 2016, Zugmeyer 2016). The Gila topminnow likely dispersed from Sonoita Creek, a tributary that merges with the Santa Cruz River upstream of the park (Cothrun et al. 2015).

In general, the electrofishing method yielded a higher CPUE than seining. CPUE for both methods was also generally higher for longfin dace and lowest for western mosquitofish across all years. CPUE (electroshocking) for the Gila topminnow was about half that of longfin dace but greater than for western mosquitofish. These results indicate larger populations of native fish than non-native fish.

Based only on electrofishing data between the two studies, native fish richness has increased and non-native fish richness has declined in the Santa Cruz River. No non-native green sunfish (*Lepomis cyanellus*) or largemouth (*Micropterus salmoides*) were caught in the Santa Gertrudis index reach from 2009 to 2017 but both species were present (in small numbers) during 2001/2002. Furthermore,

Table 64. Total fish caught and catch per unit effort for the Santa Gertrudis index reach from 2009 to 2017.

Water Year	Longfin dace			Gila topminnow			Western mosquitofish		
	Total	Electroshock (catch/min)	Seine Net (catch/m²)	Total	Electroshock (catch/min)	Seine Net (catch/m²)	Total	Electroshock (catch/min)	Seine Net (catch/m²)
2009	0	0.00	–	0	0.00	–	0	0.00	–
2010	10	–	0.02	0	–	0.00	6	–	0.01
2011	43	–	0.08	0	–	0.00	0	–	0.00
2012	510	35.25	–	0	0.00	–	11	0.76	–
2013	574	–	1.79	0	–	0.00	0	–	0.00
2014	167	23.25	–	0	0.00	–	0	0.00	–
2015	159	8.49	–	0	0.00	–	0	0.00	–
2016	186	42.76	–	113	25.95	–	3	0.69	–
2017*	107	9.53	0.00	52	4.63	0.00	0	0.00	0.00

* Fish caught via seining were not differentiated from fish caught via electrofishing. Electrofish effort may be high and seine effort may be low.

Source: 2009-2015 data were provided in Gwilliam et al. 2016. Data for 2016 and 2017 were provided by the Sonoran Institute.

non-native western mosquitofish numbers appear to have declined substantially over time. A total of 273 individuals were captured during 2001 and 2002 while only 20 individuals were captured during the last nine years combined (2009-2017). Because the Tumacácori Channel was not sampled during recent surveys, we could not determine whether non-native bluegills still occur there (a total of six individuals were captured there during 2001 and 2002). However, the side channel is wetted only during floods, if at all (NPS, E. Gwilliam, aquatic ecologist, comments to draft assessment, 2 April 2018), in which case habitat for bluegills at this location is now absent.

These results suggest improvement for native fish in the park, but the condition still warrants moderate concern because non-native western mosquitofish continue to occupy park waters and they are known competitors of native fish (Powell et al. 2005). Furthermore, although it appears that green sunfish and largemouth bass are absent in this stretch of the river, it could be that they were not captured by the survey methods because small populations are difficult to survey. Also, while the return of the Gila topminnow is encouraging, more data are needed to determine whether this species will persist. For these reasons, confidence in the condition and trend is medium.

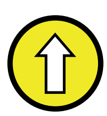
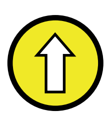
Overall Condition, Threats, and Data Gaps

Overall, fish warrant moderate concern but with an improving trend. Confidence in the condition rating is medium (Table 5). Two of the four native species known to occur in the park were absent in recent years but this may be more a function of sampling location rather than an actual absence. Although not considered in the condition rating, Gila chub (*Gila intermedia*) and desert pupfish (*Cyprinodon macularius*) were not recorded during either survey but may have historically been present in the park (Powell et al. 2005). Both species are listed as endangered by the U.S. Fish and Wildlife Service's Endangered Species Program (USFWS 2017). The former species was known to occur in the Santa Cruz River but was extirpated by 1904 (Minckley 1973 as cited in Powell et al. 2005). The Gila chub currently occurs in a few stretches of the Santa Cruz River but not near the park (Weedman et al. 1996).

The approximately 10-year absence of Gila topminnow from the Santa Cruz River in Tumacácori NHP has been attributed to a variety of factors including grazing, groundwater pumping, water diversion, drought, and the introduction of non-native species such as the western mosquitofish, American bullfrog (*Lithobates catesbeianus*), and crayfish (*Orconectes virilis*). These non-native species not only compete with native species but they are also predators (i.e., western mosquitofish and bullfrog). While western mosquitofish have apparently declined in park waters, current abundance of American bullfrogs is unknown. During the 2001 and 2002 surveys a total of 41 American bullfrogs were observed in the park (Powell et al. 2005).

Two of the most persistent threats to the Santa Cruz River is water quality and quantity. Fish are

Table 65. Summary of fish indicator, measure, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Presence/ Absence		The longfin dace and federally endangered Gila topminnow have both returned to park waters after a prolonged absence. Two additional native species (Sonoran sucker and desert sucker) observed in earlier efforts were not observed more recently, but this may be due to differences in sampling location rather than an actual absence. Additionally, non-native richness has declined, and the one remaining non-native species is apparently rare in the Santa Gertrudis index reach. Although native fish have returned, the presence of the competitive western mosquitofish warrants moderate concern. However, trend has improved. Confidence in the condition rating is medium.
Overall Condition	Summary of All Measures		Overall native richness has increased and non-native richness has declined, but the continued presence of western mosquitofish warrants moderate concern. Confidence in the overall condition rating is medium because it is uncertain without more data if the apparent trend is actually improving. Data gaps include thresholds of water quality and quantity required to maintain healthy populations of native fish in the park, especially considering increasing pressure on water resources as the human population grows.

not only inherently valuable components of stream communities, but they are also indicators of stream health. Previously high concentrations of ammonia detected in the Santa Cruz River made these waters uninhabitable for some fish species (Gwilliam et al. 2016). However, water quality has improved dramatically with the 2009 upgrade to the NIWTP (NPS 2014b, Gwilliam et al. 2016, Zugmeyer 2016). According to the 2015 water resources report for the park no Arizona State water quality standards were exceeded for a suite of measures (Gwilliam et al. 2016).

While water quality has improved, water quantity has declined. During mid-June of 2008 to 2014, water did not flow past Tubac Reach just north of the park during four of the seven years (Zugmeyer 2016). The NIWTP currently discharges ~13-15 mgd into the Santa Cruz River, most of which (9-12 mgd) originates in Mexico (NPS 2014b). An international treaty governs all but 3 mgd of this effluent, and with improved water quality, Mexico now uses approximately half of this water for agriculture and groundwater recharge (NPS 2014b). Although reduced flows can be partially attributed to this diversion, other factors such as increased water infiltration with improved water quality and fewer scouring floods have also reduced water quantity (Zugmeyer 2016).

Water quantity is also influenced by climate change. Recent climate conditions in the park and elsewhere in the desert southwest have already shifted beyond the historical range of variability (Prein et al. 2016). In Tumacácori NHP, four temperature variables were categorized as "extreme warm," which was defined as values exceeding 95% of the historical range of variability (Monahan and Fisichelli 2014). While no precipitation variables were classified as extreme dry, evaporation and transpiration, and thus dryness, will increase as the temperature warms (Monahan and Fisichelli 2014). Regardless of the reasons for reduced water quantity, dry conditions stress the aquatic and riparian environment. For example, prolonged drought leads to willow-cottonwood (*Salix* spp.-*Populus* spp.) die-off, but riparian vegetation helps shade streams and regulate water temperature for fish and other aquatic wildlife (NPS 2014b). And if prolonged periods of no-flow events continue, fish habitat will be eliminated from portions of the river.

Sources of Expertise

This assessment was written by science writer and wildlife biologist, Lisa Baril, Utah State University. Sources of expertise include the reviewers listed in Appendix A.

Bats

Background and Importance

World-wide, about one-fourth of all mammal species are bats (Tuttle 1988), and 47 bat species inhabit the United States and Canada (USFWS 2018). Twenty-seven of these species, a little over 57%, are included in Arizona's master species list for the state (AGFD 2012). Tumacácori National Historical Park's (NHP) bat researcher, Karen Krebbs, summarized the importance of bats as follows in Krebbs et al. (2018):

> Bats provide essential ecosystem services including flower pollination and seed dispersal and they are also the major predators of night flying insects. Given the large volumes of insects consumed (up to 100% of body weight per night) and the long distances traveled, bats are thought to play a major role in regulating nocturnal insect populations and in transporting nutrients across the landscape, particularly from stream corridors to tree roosts (Rainey et al. 1992). Despite the great diversity of bat species around the world and in the United States, bats are poorly studied compared to other mammals. Bats are threatened by habitat destruction, fragmentation, pollution, pesticides, human ignorance, and White-nose Syndrome. Drastic reductions in bat populations have occurred during the recent years in the United States and worldwide (Harvey et al. 1999). As human population increases, more pressure is placed on natural resources and additional bat habitat is lost.

Data and Methods

To assess the condition of bats at Tumacácori NHP, we used two indicators, species occurrence and disease occurrence, with a total of three measures: species presence/absence, species of conservation concern, and White-nose syndrome (WNS) presence/absence.

To evaluate the presence/absence of bats at the NHP, we compared the species recorded during all survey efforts at Tumacácori. The NHP's NPSpecies list for bats (NPS 2018) was not used since it listed all bat species as unconfirmed even though the surveys since 2009 have documented the presence of all but one species on the list. Tumacácori NHP's baseline inventory for mammals was conducted from 2001 to 2002 by Powell et al. (2005), however, the majority of the survey effort was focused on mammals other than bats. Only one bat roost location during one night (October 2, 2001) in and around the Tumacácori Mission structure was surveyed. Other records of bat presence at the park during the Powell et al. (2005) inventory were obtained by researchers reviewing

The Mexican long-tongued bat occurs at Tumacácori NHP. Photo Credit: NPS.

museum collections. These records were also used to assess the bat presence/absence condition measure at the park.

The majority of Tumacácori NHP's inventory of bats is derived from Krebbs et al. (2017, 2018) survey effort, which spanned from 2009-2011 and 2016-2018 and included the National Park Service's (NPS) BioBlitz event and Bat Appreciation Day during the 2016-2017 and 2017-2018 field seasons (Krebbs et al. 2017, 2018). Two reports were provided by park staff, which documented survey methods and effort for two survey seasons, July - December 2016, January - June 2017 (Krebbs et al. 2017) and November - December 2017, January - October 2018 (Krebbs et al. 2018). Specifics regarding the previous survey dates and methods were not provided but number of species per survey season were provided and are summarized in the Condition and Trend section.

Four study locations were established in the Tumacácori unit only at the Courtyard, Mission Church, Santa Cruz River, and small pond during the 2016-2017 survey. The first three sites were surveyed during the 2017-2018 season. One to two 6 m (19.7 ft) standard mist nets were established once a month (and removed during each of the 12 monthly surveys) at each study site and monitored from dusk for a minimum of two hours (Krebbs et al. 2017, 2018). Researchers also recorded bat calls for six evenings during the 2016-2017 survey and five evenings during the 2017-2018 survey using a Pettersson D 240X ultrasound bat detector. The acoustic monitoring occurred 20 - 50 m (66 - 164 ft) from the mist net sites at Mission Church and along the Santa Cruz River.

We compared the park's list of 'present' species to the U.S. Fish and Wildlife Service's federal list of endangered and threatened species that occur in Arizona (USFWS 2015) to evaluate species of conservation concern . We also reviewed species listed as greatest conservation need in Arizona (Arizona Game and Fish Department [AGFD] 2012). Under Arizona's Wildlife Action Plan, wildlife species may be listed as Tier 1A or 1B (or 1C although we do not consider those relatively lower-priority species here). Federally listed species and candidate species, as well as those for which a signed conservation agreement exists, or those that require monitoring after delisting, are included in the Tier 1A category and are considered to be of highest conservation priority (AGFD 2012).

WNS is a disease that affects hibernating bats and has resulted in the mortality of millions of bats in North America (USFWS 2018). WNS is named for the white fungus, originally known as *Geomyces destructans*, but now called *Pseudogymnoascus destructans* (USFWS 2018), that grows on the muzzle and other parts of bats' bodies (USFWS 2018). The disease is thought to spread primarily through direct contact between bats, but it is also believed possible to spread the fungus to new hibernacula on shoes, clothing, or gear (USFWS 2018).

Krebbs et al. (2017, 2018) researchers examined all of the park's captured bats for evidence of WNS during all surveys to determine whether WNS was present in bats at the park.

Reference Conditions

Reference conditions for the three measures are shown in Table 66 and are described for resources in good, moderate concern, and significant concern conditions.

Condition and Trend

Table 67 lists the 10 bat species that have been recorded at the park during the Powell et al. (2005) inventory, including previously vouchered specimens collected by other researchers, and Krebbs et al. (2017, 2018) study. Powell et al.'s (2005) limited field effort for surveying bats documented the presence of the pallid bat (*Antrozous pallidus*) only. However, based on their museum collections review, five species, including the pallid bat, were recorded at the park in previous years (years are listed in Table 67 in parentheses within the vouchered specimens column). The majority of the vouchered specimens remain unverified but these same species have been recorded during the most recent bat surveys conducted by Krebbs et al. (2017, 2018), except for one— the California myotis (*Myotis californicus*), which is housed in Saguaro National Park's museum collection.

During the Krebbs et al. (2017, 2018) surveys, a total of nine species were recorded at Tumacácori NHP, using both netting and acoustic survey methods. Table 67 lists the number of individual species captured using the netting method only, with the exception of the western red bat (*Lasiurus blossevillii)*. The red bat was first detected in 2018 by the acoustical survey method only (Krebbs et al. 2018) but was listed in Table 67 to

Table 66. Reference conditions used to assess bats.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Species Occurrence	Presence/Absence	All or nearly all of the species recorded during early surveys/ observations in the park were recorded during later surveys.	Several species recorded during early surveys were not recorded during later surveys (particularly if the species had previously been considered common at the park).	A substantial number of species recorded during early surveys were not recorded during later surveys (particularly if the species had previously been considered common at the park).
	Species of Conservation Concern	A moderate to substantial number of species of conservation concern occur in the park, which indicates that the NPS unit provides important habitat for these species and contributes to their conservation.	A low number of species of conservation concern occur in the park.	No species identified as species of conservation concern occur in the park.
Disease Occurrence	White-nose Syndrome Presence/ Absence	There is no known occurrence of White-nose-syndrome.	White-nose-syndrome is present.	White-nose-syndrome is present.

Table 67. Bat species recorded during surveys at Tumacácori NHP.

Common Name	Scientific Name	Vouchered Specimens (year)	Krebbs et al. (2018)							
			Powell et al. (2005)	2009	2010	2011	2016	2017	2018	Krebbs et al. Total
Big brown	*Eptesicus fuscus*	–	–	–	1	–		1	1	3
California leaf-nosed[1]	*Macrotus californicus*	1 (1950)	–	–	–	–	1	–	–	1
California myotis[1]	*Myotis californicus*	2 (unknown year)	–	–	–	–	–	–	–	–
Cave myotis[2]	*Myotis velifer*	80 (1937, 1950, 1951)	–	7	4	–	–	–	1	12
Lesser long-nosed	*Leptonycteris yerbabuenae*	–	–	–	11	–	2	–	2	15
Mexican free-tailed[1]	*Tadarida brasiliensis*	3 (1950)	–	4	1	1	–	2	–	8
Mexican long-tongued	*Choeronycteris mexicana*	–	–	–	5	–	–	–	2	7
Pallid[1]	*Antrozous pallidus*	4 (1938, 1950)	X	9	28	13	27	2	48	127
Western pipistrelle	*Parastrellus hesperus*	–	–	–	–	–	–	–	1	1
Western red	*Lasiurus blossevillii*	–	–	–	–	–	–	–	X	total not reported

[1] Museum specimen is unverified (Powell et al. 2005).

[2] The 1937 specimens vouchered by University of California, Berkeley were the only ones confirmed (Powell et al. 2005).

Notes: X = species present but no number provided. Numbers represent number of individuals.

account for the total number of bats recorded at the park.

Only one species, the pallid bat, was recorded every year from 2009-2011 and 2016-2018 during the Krebbs et al. surveys. The pallid bat accounted for 73% (127/174) of all individuals (*n* =174) netted by Krebbs et al. (2017, 2018) researchers and is very common in Arizona. The lesser long-nosed bat (*Leptonycteris yerbabuenae*) and cave myotis (*Myotis velifer*) were the next most abundant, representing 8.6% (15/174) and 6.9% (12/174) of all individuals netted, respectively. Each of the remaining six species represented less than 5% of the total number of individuals caught over the six year time span. The majority of individuals were captured at the Courtyard study location during the 2016-2017 and 2017-2018 sampling periods (Krebbs et al. 2017, 2018).

Between all surveys and vouchered specimens, the pallid bat was the only species recorded during all, followed by the Mexican free-tailed bat (*Tadarida brasiliensis*), which was vouchered in 1950 (Powell et al. 2005) and recorded by Krebbs et al. (2017, 2018) every year from 2009-2011 and in 2017. The cave myotis, the most previously vouchered species (vouchered in 1937, 1950, and 1951), was also recorded in 2009, 2010, and 2018 by Krebbs et al. (2017, 2018) researchers. The California leaf-nosed bat (*Macrotus californicus*) was vouchered in 1950 and recorded in 2016 (Krebbs et al. 2017, 2018). The remaining five species were not vouchered and observed during the Krebbs et al. (2017, 2018) surveys only, with varying results based on netting or acoustical methods.

A comparison of the bat species detection methods used by Krebbs et al. (2017, 2018) (net versus acoustical monitoring) during the 2017 and 2018 field seasons is presented in Table 68. The comparison is based on the number of months each method was employed. Bats were netted during every month in 2017 and 2018 while acoustic monitoring occurred during six months in 2017 and five months in 2018. The reason for the comparison is due to the fact that certain species of bats are known to be difficult to net due to their flying habits or due to physical factors present, such as the presence of abundant open water (i.e, Santa Cruz River) and that certain methods represent different amounts of time investments based on return and study purpose (e.g. abundance versus documenting species presence only). Based on the 12 months during the 2017 and 2018 field seasons, the pallid bat was the only species recorded with the highest number of months in 2017 recorded by the acoustic method and in 2018 by the netting method. The majority of species presence was confirmed via the acoustic monitoring method, except for the lesser long-nosed bat and Mexican long-tongued bat (*Choeronycteris mexicana*), which were detected by the net method only. The western red bat (*Lasiurus blossevillii*) was only detected using the acoustic method. Depending on the park's future purpose for monitoring bats,

Table 68. Comparison of bat species detected using net and acoustic survey methods during the 2017 and 2018 surveys at Tumacácori NHP.

Species	Total Number of Months Species Was Recorded		Number of Months Species Detected by Netting Method		Number of Months Species Detected by Acoustic Method		Most Common Detection Method for Each Species (net or acoustic)	
	2017 *n* = 12	2018 *n* = 12	2017 *n* = 12	2018 *n* =12	2017 *n* = 6	2018 *n* = 5	2017	2018
Big brown	6	6	1	1	6	5	Acoustic+	Acoustic+
California leaf-nosed	2	0	1	0	2	0	Acoustic+	–
Cave myotis	3	4	0	1	3	3	Acoustic only	Acoustic+
Lesser long-nosed	1	1	1	1	0	0	Net only	Net only
Mexican free-tailed	3	2	1	0	3	2	Acoustic+	Acoustic only
Mexican long-tongued	0	2	0	2	0	0	–	Net only
Pallid	9	10	5	6	6	5	Acoustic+	Net+
Western pipistrelle	5	3	0	1	5	3	Acoustic only	Acoustic+
Western red	3	2	0	0	3	2	Acoustic only	Acoustic only

Sources: Krebbs et al. (2017, 2018).

Note: + next to method type represents that the species was detected more often during that survey approach.

efficiency of method may be considered based on staff availability and funding, especially given the fact that the acoustical monitoring effort was 50-60% less than the netting method but detected six to seven species more often than the labor intensive netting method.

To provide additional context of Tumacácori NHP's bat species presence/absence measure within national parks, we reviewed the results from a macroecological study of bat conservation in the NPS (Rodhouse et al. 2016). NPSpecies bat occurrence records in national parks were compared to published range maps for bats. Only 55 (19%) of parks had ≥90% of the bat species expected, which may suggest either under-reporting and/or under-sampling (Rodhouse et al. 2016). The area in southeastern Arizona shows a high potential species richness and the NPSpecies presence records revealed that the number of bat species present ranges from 11-21, representing one of the most bat-diverse areas in the continental U.S. (Rodhouse et al. 2016).

Bat species richness was strongly correlated with park area, latitude, elevation, and underground habitat, which may partially explain why only nine species have been confirmed at Tumacácori NHP to date. While Krebbs et al. (2017, 2018) researchers confirmed the presence of several species that Powell et al. (2005) listed as 'may occur' at the park, 14 species remain unverified, but expected, based on the habitat and range maps produced by Burt and Grossenheider (1976) and/or Hoffmesiter (1986). Given the fact that eight of the 10 species have been recently observed at the park, we consider bat presence/absence to be good with high confidence; however, trend is unknown.

The Species of Greatest Conservation Need identified in the Arizona State Wildlife Action Plan (AGFD 2012) lists five species of bats that have been observed at the park. Only one, the lesser long-nosed bat, is listed as a Tier 1A species, which warrants the highest degree of protection. Three, western red, California leaf-nosed, and Mexican free-tailed, are listed as Tier 1B species. Only one, Mexican long-tongued bat, is listed as a Tier 1C species. These are species "for which insufficient information is available to fully assess the vulnerabilities and therefore need to be watched for signs of stress" (AGFD 2012).

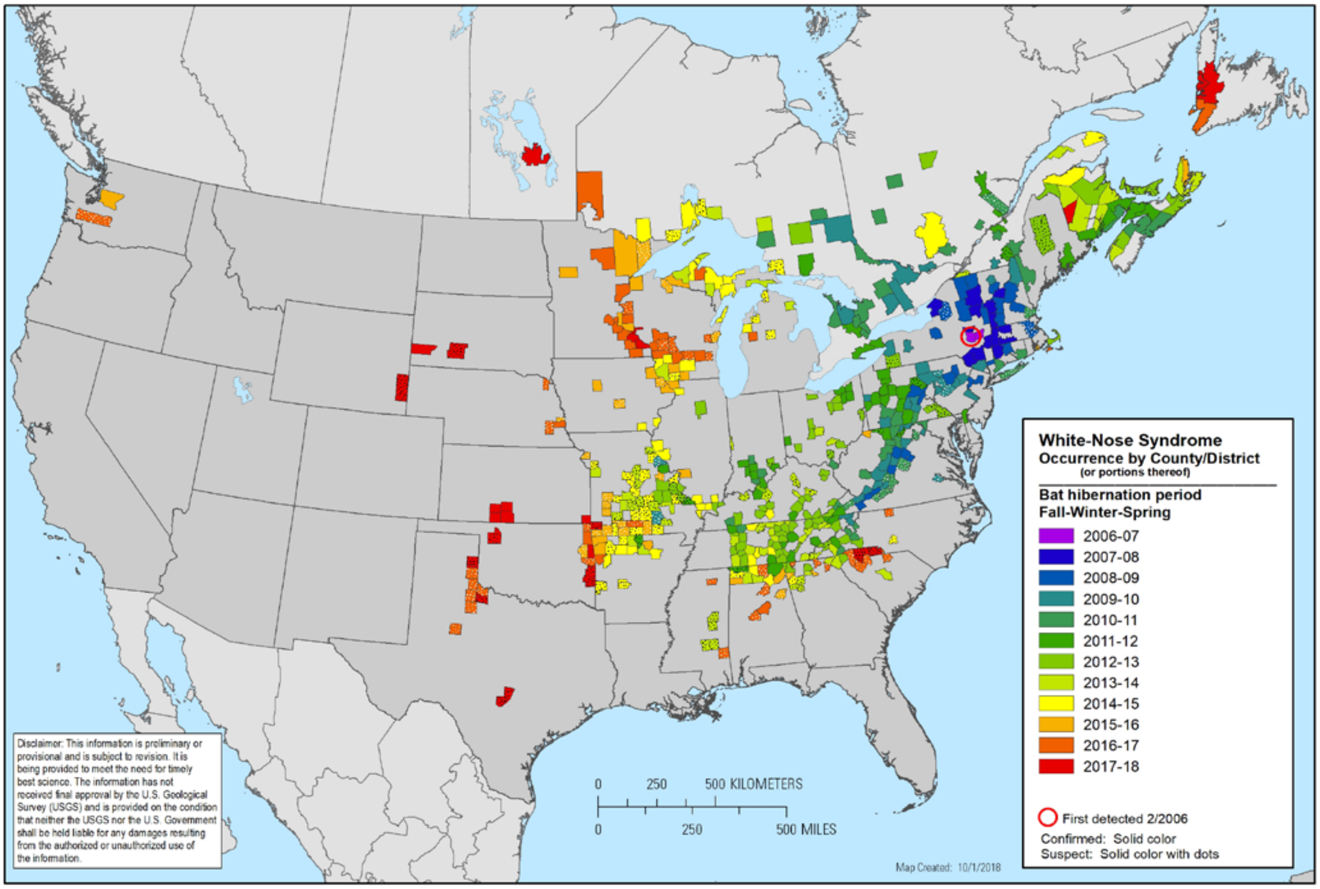
Since over 55% of the bat species that have been recorded at the park (not including the California myotis because the only specimen for the park remains unconfirmed) are listed as Arizona's species of greatest conservation need, we consider the park to provide important habitat for these species, which warrants a good condition with an unknown trend and medium confidence.

<u>White-nose Syndrome Presence/Absence</u>
None of the examined bats at the park showed any signs of WNS (Krebbs et al. 2017, 2018). Because of this, the current condition is good with high confidence. Although, it's forecasted that by the year 2026, WNS will have spread to locations in Arizona as well as several additional western states (Rodhouse et al. 2016). While the current trend is unknown, it's likely to decline as WNS continues spreading west.

Of the 11 species with diagnostic symptoms of WNS in the U.S., two, big brown bat (*Eptesicus fuscus*) and cave myotis, occur at Tumacácori NHP. Of the six bat species and two subspecies on which *Pseudogymnoascus destructans* has been detected, but no diagnostic sign of WNS has been documented, one, Mexican free-tailed bat, occurs at the NHP. As of October 1, 2018, the closest state to Arizona with confirmed cases of WNS is Texas (Figure 21, USFWS 2018).

Overall Condition, Threats, and Data Gaps
To assess the condition of bats at Tumacácori NHP, we used two indicators and a total of three measures, which are summarized in Table 69. The combined measure condition ratings result in a good condition with an unknown trend. Two key uncertainties include whether most of the bat species have been captured at the park and the degree of impact from WNS as the disease continues to spread westerly.

The loss of habitat is the primary threat to bats worldwide (BCI 2019), and given Arizona's ever-increasing population and urbanization, conversion of natural land cover is of great concern. An additional threat is the spread of WNS. In some areas where WNS has been found, it has caused an almost 100% mortality rate (BCI 2019). Also, wind turbine blades have killed thousands of bats annually (BCI 2019). These issues occur on a landscape-scale and underscore the importance of organizing a regional, multi-agency monitoring and management program to effectively protect these species.



Citation: White-nose syndrome occurrence map - by year (2018). Data Last Updated: 10/1/2018. Available at: https://www.whitenosesyndrome.org/resources/map.

Figure 21. Map showing the occurrence of White-nose syndrome, dated 10/1/18. Figure Credit: © www.whitenosesyndrome.org.

Table 69. Summary of bat indicators, measures, and condition rationale.

Indicators	Measures	Condition/ Trend/ Confidence	Rationale for Condition
Species Occurrence	Presence/ Absence		The current condition of bats presence/absence is good with the majority of species recorded during the last survey efforts, which occurred in field seasons 2017 and 2018. Confidence is high given the recent age of the data and repeatable study methods.
	Species of Conservation Concern		Five of the park's bat species are listed by AGFD (2012) as species of conservation need, representing over 55% of the bats that have been observed at the park. As a result, we consider the park to provide important habitat for these species, which warrants a good condition with an unknown trend and medium confidence.
Disease Occurrence	White-nose Syndrome Presence/ Absence		None of the examined bats showed evidence of White-nose syndrome. As a result, the current condition is good with high confidence. Although, it's forecasted that by the year 2026, the disease will have spread to most western states in the U.S., including Arizona.
Overall Condition	Summary of All Measures		The overall condition of bats is good at the park, but there is uncertainty about the lower number of bats detected than what is expected based on the macroecological study of bat conservation in national parks. Thus, the confidence level is medium. Trend is unknown.

While, some bat species are able to fly above or below netting, ultrasonic detectors may provide a means to more thoroughly document the presence (and absence) of bats at Tumacácori NHP. Although as Powell et al. (2006) stated, “not all of the mammal species would use the building structures or vegetation for any significant amount of time.” Many may just pass through the park en route to other locales, which also provides a service to these increasingly threatened mammals. Acoustic monitoring also doesn’t provide information about the health, gender, reproductive status, or the presence of WNS.

From a cultural perspective, bat guano threatens the integrity of the Mission San José de Tumacácori structure, requiring an integrated pest management approach at the park to protect all resources for which the park was established (NPS 2014a).

Sources of Expertise

Kim Struthers, NRCA Coordinator and Science Writer/Editor with Utah State University, authored this assessment.

View of Santa Cruz River along Anza Trail. Photo Credit: NPS.

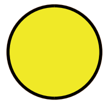
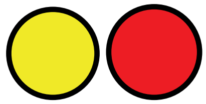
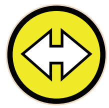
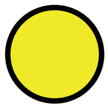
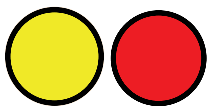
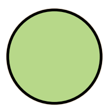
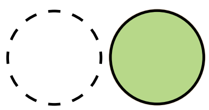
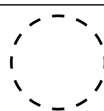
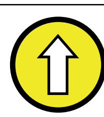
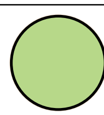
Discussion

The majority of the natural resources assessed for Tumacácori National Historical Park's (NHP) Natural Resource Condition Assessment (NRCA) are in moderate condition except for the wildlife resources—birds and mammals,— which are in good condition (Table 70). The condition of amphibians, reptiles, and small mammals is unknown due to the lack of repeat surveys from which to compare presence/absence. However, bats and medium and large-sized mammals are routinely monitored at the park and are in good condition.

Managing the park's natural resources in light of current and rapidly changing environmental conditions such as increasing temperatures, decreasing precipitation, increasing populations of non-native species (e.g., western mosquitofish (*Gambusia affinis*), American bullfrog (*Lithobates catesbeianus*), and crayfish (*Orconectes virilis*) is challenging, but paramount to resource preservation. Through collaborative partnerships, land managers and scientists are better able to define and work towards resilient landscapes capable of adapting to these ever-changing environmental stressors. One of these landscapes is the 16,114-ha (39,818-ac) subwatershed, Mavis Wash-Santa Cruz River, in which the Tumacácori unit is located. This subwatershed was evaluated in FY 2011 by the U.S. Forest Service (USFS), using the Watershed Condition Framework (WCF) (results are shown in Table 71). However, the subwatershed condition for the park's Guevavi and Calabazas units was not evaluated.

The USFS defines the WCF as "a comprehensive approach for proactively implementing integrated restoration on priority watersheds on national forests and grasslands." Twelve indicators serve as proxies representing the "underlying ecological, hydrological, and geomorphic functions and processes that affect watershed condition" (USFS 2011). The WCF is designed to "foster integrated ecosystem-based watershed assessments; target programs of work in watersheds that have been identified for restoration; enhance communication and coordination with

Table 70. Natural resource condition summary for Tumacácori NHP.

Resource	Overall Condition
Air Quality	
Hydrology	
Water Quality	
Upland Vegetation and Soils	
Riparian and Aquatic Vegetation	
Birds	
Mammals	
Herpetofauna	
Fish	
Bats	

external agencies and partners [such as the historical park]; and improve national-scale reporting and monitoring of program accomplishments. The WCF provides the USFS with an outcome-based performance measure for documenting improvement to watershed condition at forest, regional, and national scales" (USFS 2011).

The WCF evaluation for the Mavis Wash-Santa Cruz River subwatershed was rated as functioning at risk in (FY) 2011, with 6/11 indicators considered to be in fair condition. Four of these indicators are in the aquatic physical and biological groups, which pertain to the water-based resources within the subwatershed. In general, these results align with the water-related NRCA condition results. One exception is the water quality condition, which was of moderate concern at the park level but considered to be in good condition at the subwatershed level. Water quality has in fact greatly improved in recent years and is expected to continue, but as a result, water quantity has declined (Zugmeyer 2016). In addition, extended regional drought that began in 2000 has continued through WY2017, which exacerbates water withdrawal-related issues. One visible impact was expressed in the form of riparian trees dropping their leaves due to the drought-related stress. However, as a result of agricultural abandonment in the area since the 1930s, riparian obligate plants along the riparian corridor have increased (Buckley 2012).

The WCF results for the terrestrial physical and biological indicators are varied. The terrestrial physical indicators include roads and trails and associated mass wasting, along with soil erosion, contamination, and productivity. Fire regime is also in this group and is one of two (total) indicators in poor condition. This condition rating is also reflected in the NRCA's upland vegetation monitoring fire hazard indicator, which warranted moderate to significant concern at the park due to the high grass to forb cover and the high ratio of annual to total plant cover. The WCF terrestrial biological indicators include rangeland vegetation, terrestrial invasive plant species, and insects and disease. The rangeland vegetation is in poor condition, invasive species are in fair condition, and forest health is in good condition throughout the subwatershed.

Despite the moderate and significant concern ratings, the wildlife that depend on the water and vegetation resources within the park are in good condition. The bird richness of 186 species is primarily associated with the park's riparian habitat. The recolonization of native fish to the Santa Cruz River resulted in an improving trend for this resource. And the general increase in riparian obligate plants along the river's corridor, continues to support both resident and migrating species.

Since the first WCF assessment, an additional WCF one was completed in (FY) 2017 for approximately one-fourth of the subwatersheds because of changing conditions or new information (USFS 2017).

Table 71. USFS Watershed Condition Framework (WCF) (2011) assessment for aquatic and terrestrial systems in the Mavis Wash - Santa Cruz River subwatershed.

WCF Resource Group	WCF Core Indicator	WCF Core Attributes	Mavis Wash-Santa Cruz River Subwatershed Condition
Aquatic Physical	Water Quality	Impaired Waters (503d Listed) Water Quality (Unlisted)	🟢
	Water Quantity	Flow Characteristics	🟡
	Aquatic Habitat	Habitat Fragmentation Large Woody Debris Channel Shape & Function	🟡
Aquatic Biological	Aquatic Biota	Life Form Presence Native Species Exotic and/or Invasive Species	🟡
	Riparian/Wetland Vegetation	Vegetation Condition	🟡
Terrestrial Physical	Roads & Trails	Open Road Density Road Maintenance Proximity to Water Mass Wasting	🟢
	Soils	Soil Productivity Soil Erosion Soil Contamination	🟡
	Fire Regime	Fire Condition Class Wildfire Effects	🔴
Terrestrial Biological	Forest Cover	Loss of Forest Cover	n/a
	Rangeland Vegetation	Vegetation Condition	🔴
	Invasive Species	Extent and Rate of Spread	🟡
	Forest Health	Insects and Disease Ozone	🟢

Two-hundred and ninety-one of these were then identified as priority based on "agency restoration priorities, the urgency of management action to address conditions and threats to the watershed, or alignment with partner strategies and priorities" (USFS 2017). The Mavis Wash-Santa Cruz River is not one of those watersheds evaluated in (FY) 2017.

Not only is land use change a primary threat to the park's and subwatershed's resource conditions but increasing temperature and decreasing precipitation are significant resource drivers as well.

In 2012, Monahan and Fischelli (2014) evaluated which of 240 NPS parks have experienced extreme climate changes during the last 10-30 years, including Tumacácori NHP. Twenty-five climate variables (i.e., temperature and precipitation) were evaluated to determine which ones were either within <5th percentile or >95th percentile relative to the historical range of variability (HRV) from 1901-2012. Results for Tumacácori NHP were reported as follows:

- Four temperature variables were "extreme warm" (annual mean temperature, minimum temperature of the coldest month, mean temperature of the warmest quarter, mean temperature of the coldest quarter).
- No temperature variables were "extreme cold."
- No precipitation variables were "extreme dry."
- No precipitation variables were "extreme wet."

Results for the temperature of each year between 1901-2012, the averaged temperatures over progressive 10-year intervals, and the average temperature of 2003-2012 (the most recent interval) are shown in Figure 22. The blue line shows temperature for each year, the gray line shows temperature averaged over progressive 10-year intervals (10-year moving windows), and the red asterisk shows the average temperature of the most recent 10-year moving window (2003–2012). The most recent percentile is calculated as the percentage of values on the gray line that fall below the red asterisk. The results indicate that recent climate conditions have already begun shifting beyond the HRV, with the 2003-2012 decade representing the warmest on record for the park (Monahan and Fisichelli 2014).

Given the fact that climate change and land-use practices affecting park resources are functioning on a landscape-scale level, establishing partnerships with surrounding land managers and private citizens provides opportunities for achieving shared conservation goals. Considering management objectives and subsequent actions and goals from a strategic, landscape-scale perspective will more likely maintain or improve resource conditions within the park and throughout the region since most resources rely on factors that transcend political boundaries for their survival needs. Furthermore, considering conditions between closely related resources or "through the lens of" important topics and issues, may assist managers by providing an integrated and holistic approach to resource stewardship (NPS 2017b), especially given the fact that most parks face the reality of lack of personnel and restricted budgets to support the management actions necessary for continued resource condition improvements now and into the future.

Bee alighting flower. Photo Credit: © Lauren Hillquist.

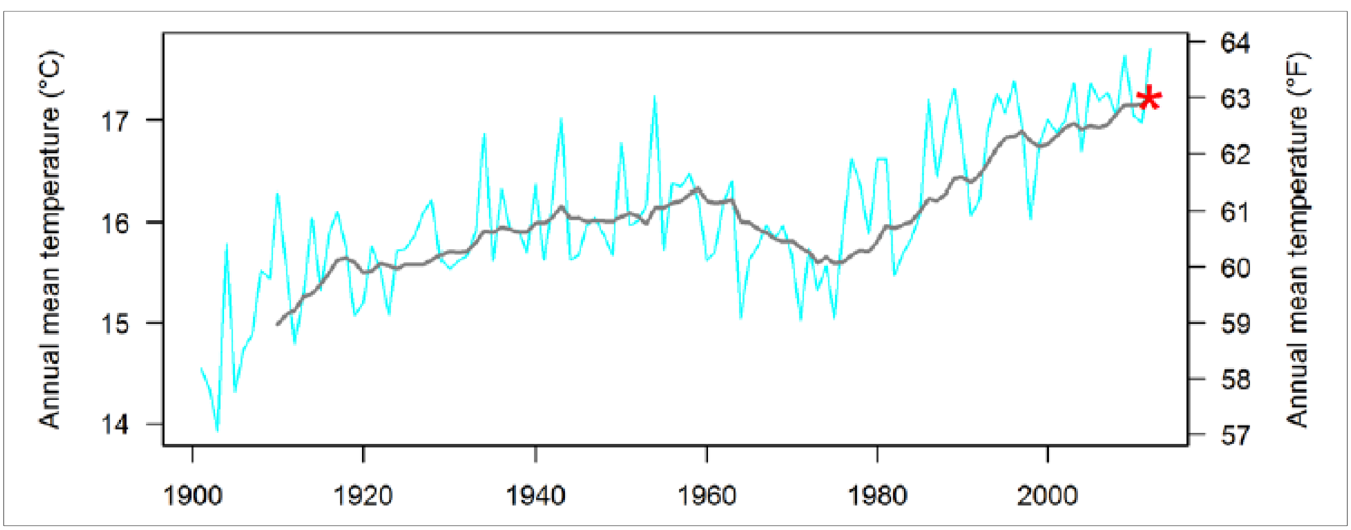


Figure 22. Time series used to characterize the historical range of variability and most recent percentile for annual mean temperature at Tumacácori NHP (including areas within 30-km [18.6-mi] of the park's boundary). Figure Credit: NPS/Monahan and Fisichelli 2014.

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Appendix A. Report Reviewers

Table A-1. Report reviewers.

Name	Affiliation and Position Title	Sections Reviewed or Other Role
Jeff Albright	National Park Service Water Resources Division, Natural Resource Condition Assessment Series Coordinator	Washington-level Program Manager
Phyllis Pineda Bovin	National Park Service WASO Denver Service Center Planning Division, Natural Resource Specialist	Regional Program Level Coordinator and Peer Review Manager
Kelly Adams and Todd Wilson	National Park Service, Grants and Contracting Officers	Executed Agreements
Fagan Johnson	National Park Service Inventory & Monitoring Division, Web and Report Specialist	Washington-level Publishing and 508 Compliance Review
Alyssa McGinnity	Managed Business Solutions, a Sealaska Company Contractor to DOI, National Park Service	Washington-level Publishing and 508 Compliance Review
Drew Jackson	National Park Service Tumacácori National Historical Park, Biological Technician	Bats Assessment
Ksienya Taylor	National Park Service Air Resources Division, Natural Resource Specialist	Air Quality Assessment
Don Weeks	National Park Service, Intermountain Regional Office, Natural Resources Division, Physical Resources Program Manager	Hydrology Assessment
Kerensa King	National Park Service Water Resources Division, Contaminants Specialist	Water Quality Assessment
Kara Raymond	National Park Service Southern Arizona Office, Hydrologist	Hydrology, Water Quality, Riparian & Aquatic Vegetation, and Herpetofauna Assessments
Bryan Hamilton	National Park Service Great Basin National Park, Wildlife Biologist	Herpetofauna Assessment
Kristen Philbrook	National Park Service Intermountain Region Office, Wildlife Biologist	Birds and Mammals Assessments
Jonathan Horst	Tucson Audubon Society, Director of Conservation and Research, Ecologist	Birds Assessment
Melissa Trammel	National Park Service Intermountain Region, Fisheries Biologist	Fish Assessment
Donna Shorrock	U.S. Forest Service, Rocky Mountain Regional Office, Regional Vegetation Ecologist, Research Natural Areas Coordinator	Upland Vegetation Assessment
Sarah Studd	National Park Service Sonoran Desert Inventory and Monitoring Network, Vegetation Ecologist	Riparian & Aquatic Vegetation and Upland Vegetation Assessment
Evan Gwilliam	National Park Service Sonoran Desert Inventory and Monitoring Network, Ecologist	Fish Assessment
Karen Krebbs	Conservation Biologist	Bats Assessment

Appendix B. Tumacácori NHP Bird List

Listed in the table below are the bird species reported for Tumacácori National Historical Park according to NPSpecies (NPS 2017) and the 2007-2015 Sonoran Desert Network (SODN) annual landbird monitoring surveys (Beaupré et al. 2013). For descriptions of each survey effort, see the Data and Methods section of the birds condition assessment. Scientific names and common names were updated to reflect current taxonomy according to the American Ornithological Society (AOS 2017). A total of 211 species are contained in the table, 182 of which are considered present in park according to NPSpecies (NPS 2017). The remaining 29 species are unconfirmed (23), probably present (2), or were reported by SODN but not listed in NPSpecies (4). Species that have been reported but were listed as not present or false reports were excluded from the table. Several species were only reported by SODN.

Table B-1. Bird species list for Tumacácori NHP.

Common Name	Scientific Name	Occurrence	Abundance	NPSpecies Tags	SODN Riparian Surveys
Abert's towhee	*Melozone aberti*	Present	Common	Breeder	X
American bittern	*Botaurus lentiginosus*	Unconfirmed	–	–	–
American goldfinch	*Spinus tristus*	Probably Present	–	–	–
American kestrel	*Falco sparverius*	Present	Uncommon	Breeder	X
American pipit	*Anthus rubescens*	Present	Uncommon	Migratory	–
American robin	*Turdus migratorius*	Present	Uncommon	Migratory	X
Anna's hummingbird	*Calypte anna*	Present	Uncommon	Breeder	X
Ash-throated flycatcher	*Myiarchus cinerascens*	Present	Common	Breeder	X
Band-tailed pigeon	*Patagioenas fasciata*	Unconfirmed	–	–	–
Bank swallow	*Riparia riparia*	Present	Rare	Migratory	–
Barn owl	*Tyto alba*	Present	Rare	Resident	–
Barn swallow	*Hirundo rustica*	Present	Common	Breeder	X
Bell's vireo	*Vireo bellii*	Present	Common	Breeder	X
Belted kingfisher	*Megaceryle alcyon*	Present	Rare	Migratory	X
Bendire's thrasher	*Toxostoma bendirei*	Unconfirmed	Rare	Migratory	–
Bewick's wren	*Thryomanes bewickii*	Present	–	–	X
Black phoebe	*Sayornis nigricans*	Present	Common	Breeder	X
Black vulture	*Coragyps atratus*	Present	Common	Breeder	X
Black-bellied whistling duck	*Dendrocygna autumnalis*	Present	Common	Resident	X
Black-chinned hummingbird	*Archilochus alexandri*	Present	Uncommon	Resident	X
Black-chinned sparrow	*Spizella atrogularis*	Unconfirmed	Common	Breeder	–
Black-crowned night-heron	*Nycticorax nycticorax*	Present	–	–	–
Black-headed grosbeak	*Pheucticus melanocephalus*	Present	Rare	Migratory	X
Black-necked stilt	*Himantopus mexicanus*	Unconfirmed	Uncommon	Migratory	–
Black-tailed gnatcatcher	*Polioptila melanura*	Present	–	–	X
Black-throated gray warbler	*Setophaga nigrescens*	Present	Uncommon	Breeder	X
Black-throated sparrow	*Amphispiza bilineata*	Present	Uncommon	Migratory	X

[1] Formerly known as sage sparrow (*Amphispiza belli*) was split into two species: Bell's vireo (*A. belli*) and sagebrush sparrow (*A nevadensis)*. NPSpecies lists the former sage sparrow. Both species may occur in the park (Martin and Carlson 1998, AOS 2017).

[2] Southwestern subspecies (*E. t. extimus*) is listed by the U.S. Fish and Wildlife Service's Endangered Species Program as Endangered (USFWS 2017). The subspecies was reported by Powell et al. (2005).

[3] The western distinct population, which includes Arizona, is listed as Threatened by the U.S. Fish and Wildlife Service's Endangered Species Program (USFWS 2017).

[4] Non-native species.

Note: X = species present.

Table B-1 continued. Bird species list for Tumacácori NHP.

Common Name	Scientific Name	Occurrence	Abundance	NPSpecies Tags	SODN Riparian Surveys
Blue grosbeak	*Passerina caerulea*	Present	Common	Breeder	X
Blue-gray gnatcatcher	*Polioptila caerulea*	Present	Common	Breeder	X
Blue-throated hummingbird	*Lampornis clemenciae*	Unconfirmed	Uncommon	Migratory	–
Brewer's blackbird	*Euphagus cyanocephalus*	Present	Uncommon	Migratory	–
Brewer's sparrow	*Spizella breweri*	Present	Common	Resident	X
Bridled titmouse	*Baeolophus wollweberi*	Present	Uncommon	Breeder	X
Broad-billed hummingbird	*Cynanthus latirostris*	Present	Common	Breeder	X
Broad-tailed hummingbird	*Selasphorus platycercus*	Present	Uncommon	Migratory	X
Bronzed cowbird	*Molothrus aeneus*	Present	Uncommon	Breeder	X
Brown creeper	*Certhia americana*	Present	Rare	Resident	–
Brown thrasher	*Toxostoma rufum*	Unconfirmed	–	–	–
Brown-crested flycatcher	*Myiarchus tyrannulus*	Present	Common	Breeder	X
Brown-headed cowbird	*Molothrus ater*	Present	Common	Breeder	X
Buff-collared nightjar	*Antrostomus ridgwayi*	Unconfirmed	–	–	–
Bullock's oriole	*Icterus bullockii*	Present	Uncommon	Breeder	X
Burrowing owl	*Athene cunicularia*	Unconfirmed	–	–	–
Bushtit	*Psaltriparus minimus*	Present	Uncommon	Resident	X
Cactus wren	*Campylorhynchus brunneicapillus*	Present	Common	Breeder	X
Calliope hummingbird	*Selasphorus calliope*	Present	Rare	Migratory	–
Canyon towhee	*Melozone fusca*	Present	Uncommon	Breeder	X
Cassin's kingbird	*Tyrannus vociferans*	Present	Common	Breeder	X
Cassin’s sparrow	*Peucaea cassinii*	Present	Rare	Migratory	X
Cassin’s vireo	*Vireo cassinii*	Present	Uncommon	Migratory	X
Cedar waxwing	*Bombycilla cedrorum*	Present	Uncommon	Migratory	X
Chihuahuan raven	*Corvus cryptoleucus*	Present	Uncommon	Resident	X
Chipping sparrow	*Spizella passerina*	Present	Uncommon	Resident	X
Cliff swallow	*Petrochelidon pyrrhonota*	Present	Uncommon	Migratory	X
Common black hawk	*Buteogallus anthracinus*	Present	Uncommon	Migratory	X
Common ground-dove	*Columbina passerina*	Present	Common	Breeder	X
Common poorwill	*Phalaenoptilus nuttallii*	Present	Rare	Migratory	
Common raven	*Corvus corax*	Present	Common	Breeder	X
Common yellowthroat	*Geothlypis trichas*	Present	Uncommon	Breeder	X
Cooper's hawk	*Accipiter cooperii*	Present	Uncommon	Breeder	X
Cordilleran flycatcher	*Empidonax occidentalis*	Unconfirmed	–	–	–
Costa’s hummingbird	*Calypte costae*	Present	Rare	Migratory	X
Crissal thrasher	*Toxostoma crissale*	Present	Uncommon	Breeder	X
Curve-billed thrasher	*Toxostoma curvirostre*	Present	Common	Breeder	X
Dark-eyed junco	*Junco hyemalis*	Present	Uncommon	Resident	–

[1] Formerly known as sage sparrow (*Amphispiza belli*) was split into two species: Bell’s vireo (*A. belli*) and sagebrush sparrow (*A nevadensis)*. NPSpecies lists the former sage sparrow. Both species may occur in the park (Martin and Carlson 1998, AOS 2017).

[2] Southwestern subspecies (*E. t. extimus*) is listed by the U.S. Fish and Wildlife Service’s Endangered Species Program as Endangered (USFWS 2017). The subspecies was reported by Powell et al. (2005).

[3] The western distinct population, which includes Arizona, is listed as Threatened by the U.S. Fish and Wildlife Service’s Endangered Species Program (USFWS 2017).

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Note: X = species present.

Table B-1 continued. Bird species list for Tumacácori NHP.

Common Name	Scientific Name	Occurrence	Abundance	NPSpecies Tags	SODN Riparian Surveys
Double-crested cormorant	*Phalacrocorax auritus*	Present	Rare	Migratory	–
Dusky flycatcher	*Empidonax oberholseri*	Present	Uncommon	Migratory	–
Dusky-capped flycatcher	*Myiarchus tuberculifer*	Present	Uncommon	Breeder	X
Eastern phoebe	*Sayornis phoebe*	Present	Occasional	Vagrant	–
Eastern towhee	*Pipilo erythrophthalmus*	Unconfirmed	–	–	–
Elegant trogon	*Trogon elegans*	Unconfirmed	–	–	–
Elf owl	*Micrathene whitneyi*	Present	Uncommon	Breeder	–
Eurasian collared-dove[4]	*Streptopelia decaocto*	Present	Uncommon	Resident	X
European starling[4]	*Sturnus vulgaris*	Present	Common	Breeder	X
Franklin's gull	*Leucophaeus pipixcan*	–	–	–	X
Gambel's quail	*Callipepla gambelii*	Present	Common	Breeder	X
Gila woodpecker	*Melanerpes uropygialis*	Present	Common	Breeder	X
Gilded flicker	*Colaptes chrysoides*	Present	Uncommon	Breeder	X
Golden eagle	*Aquila chrysaetos*	Present	Rare	Migratory	–
Grace's warbler	*Setophaga graciae*	Unconfirmed	–	–	–
Gray catbird	*Dumetella carolinensis*	Unconfirmed	–	–	–
Gray flycatcher	*Empidonax wrightii*	–	–	–	X
Gray hawk	*Buteo plagiatus*	Present	Uncommon	Breeder	X
Gray vireo	*Vireo vicinior*	Present	Rare	Migratory	X
Great blue heron	*Ardea herodias*	Present	Uncommon	Breeder	X
Great egret	*Ardea alba*	Present	Rare	Migratory	–
Great horned owl	*Bubo virginianus*	Present	Uncommon	Breeder	X
Greater roadrunner	*Geococcyx californianus*	Present	Uncommon	Breeder	X
Great-tailed grackle	*Quiscalus mexicanus*	Present	Common	Resident	X
Green heron	*Butorides virescens*	Unconfirmed	–-	Migratory	–
Green kingfisher	*Chloroceryle americana*	Present	Rare	Resident	–
Green-tailed towhee	*Pipilo chlorurus*	Present	Uncommon	Resident	X
Hairy woodpecker	*Picoides villosus*	Unconfirmed	–	–	–
Hammond's flycatcher	*Empidonax hammondii*	Present	Uncommon	Migratory	–
Harris's hawk	*Parabuteo unicinctus*	Present	Occasional	Resident	X
Hepatic tanager	*Piranga flava*	Present	Rare	Migratory	X
Hermit thrush	*Catharus guttatus*	Present	Uncommon	Resident	X
Hooded oriole	*Icterus cucullatus*	Present	Uncommon	Breeder	X
Horned lark	*Eremophila alpestris*	Unconfirmed	–	–	–
House finch	*Carpodacus mexicanus*	Present	Common	Breeder	X
House sparrow[4]	*Passer domesticus*	Present	Common	Breeder	X
House wren	*Troglodytes aedon*	Present	Uncommon	Resident	X
Hutton's vireo	*Vireo huttoni*	Present	Rare	Migratory	X
Inca dove	*Columbina inca*	Present	Uncommon	Breeder	X

[1] Formerly known as sage sparrow (*Amphispiza belli*) was split into two species: Bell's vireo (*A. belli*) and sagebrush sparrow (*A nevadensis)*. NPSpecies lists the former sage sparrow. Both species may occur in the park (Martin and Carlson 1998, AOS 2017).

[2] Southwestern subspecies (*E. t. extimus*) is listed by the U.S. Fish and Wildlife Service's Endangered Species Program as Endangered (USFWS 2017). The subspecies was reported by Powell et al. (2005).

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[4] Non-native species.

Note: X = species present.

Table B-1 continued. Bird species list for Tumacácori NHP.

Common Name	Scientific Name	Occurrence	Abundance	NPSpecies Tags	SODN Riparian Surveys
Indigo bunting	*Passerina cyanea*	Present	Uncommon	Breeder	X
Killdeer	*Charadrius vociferus*	Present	Uncommon	Breeder	
Ladder-backed woodpecker	*Picoides scalaris*	Present	Common	Breeder	X
Lark sparrow	*Chondestes grammacus*	Present	Uncommon	Resident	X
Lazuli bunting	*Passerina amoena*	Present	Uncommon	Breeder	X
Lesser goldfinch	*Carduelis psaltria*	Present	Common	Breeder	X
Lesser nighthawk	*Chordeiles acutipennis*	Present	Uncommon	Breeder	–
Lewis's woodpecker	*Melanerpes lewis*	Present	Occasional	Migratory	–
Lincoln's sparrow	*Melospiza lincolnii*	Present	Uncommon	Resident	–
Loggerhead shrike	*Lanius ludovicianus*	Present	Rare	Migratory	–
Louisiana waterthrush	*Parkesia motacilla*	Present	Occasional	Resident	–
Lucy's warbler	*Oreothlypis luciae*	Present	Common	Breeder	X
MacGillivray's warbler	*Geothlypis tolmiei*	Present	Uncommon	Migratory	X
Mallard	*Anas platyrhynchos*	Present	Uncommon	Resident	X
Marsh wren	*Cistothorus palustris*	Present	Rare	Migratory	–
Merlin	*Falco columbarius*	Present	Rare	Migratory	–
Mississippi kite	*Ictinia mississippiensis*	Present	Rare	Vagrant	–
Montezuma quail	*Cyrtonyx montezumae*	Unconfirmed	–	–	–
Mountain bluebird	*Sialia currucoides*	Present	Occasional	Migratory	–
Mourning dove	*Zenaida macroura*	Present	Common	Breeder	X
Nashville warbler	*Oreothlypis ruficapilla*	Present	Uncommon	Migratory	X
Northern beardless tyrannulet	*Camptostoma imberbe*	Present	Uncommon	Breeder	X
Northern cardinal	*Cardinalis cardinalis*	Present	Common	Breeder	X
Northern flicker	*Colaptes auratus*	Present	Common	Resident	X
Northern harrier	*Circus cyaneus*	Present	Uncommon	Migratory	X
Northern mockingbird	*Mimus polyglottos*	Present	Common	Breeder	X
Northern parula	*Setophaga americana*	Present	Occasional	Vagrant	–
Northern rough-winged swallow	*Stelgidopteryx serripennis*	–	–	–	X
Northern waterthrush	*Parkesia noveboracensis*	Present	Rare	Migratory	–
Olive-sided flycatcher	*Contopus cooperi*	Present	Rare	Migratory	X
Orange-crowned warbler	*Oreothlypis celata*	Present	Uncommon	Migratory	X
Ovenbird	*Seiurus aurocapilla*	Present	Occasional	Vagrant	–
Pacific-slope flycatcher	*Empidonax difficilis*	Present	Uncommon	Migratory	X
Painted bunting	*Passerina ciris*	Present	Occasional	Vagrant	–
Peregrine falcon	*Falco peregrinus*	Present	Uncommon	Migratory	–
Phainopepla	*Phainopepla nitens*	Present	Common	Breeder	X
Pine siskin	*Spinus pinus*	Present	Uncommon	Migratory	X

[1] Formerly known as sage sparrow (*Amphispiza belli*) was split into two species: Bell's vireo (*A. belli*) and sagebrush sparrow (*A nevadensis)*. NPSpecies lists the former sage sparrow. Both species may occur in the park (Martin and Carlson 1998, AOS 2017).

[2] Southwestern subspecies (*E. t. extimus*) is listed by the U.S. Fish and Wildlife Service's Endangered Species Program as Endangered (USFWS 2017). The subspecies was reported by Powell et al. (2005).

[3] The western distinct population, which includes Arizona, is listed as Threatened by the U.S. Fish and Wildlife Service's Endangered Species Program (USFWS 2017).

[4] Non-native species.

Note: X = species present.

Table B-1 continued. Bird species list for Tumacácori NHP.

Common Name	Scientific Name	Occurrence	Abundance	NPSpecies Tags	SODN Riparian Surveys
Plumbeous vireo	*Vireo plumbeus*	Present	Uncommon	Migratory	X
Purple martin	*Progne subis*	Present	Uncommon	Breeder	X
Pyrrhuloxia	*Cardinalis sinuatus*	Present	Uncommon	Breeder	X
Red-tailed hawk	*Buteo jamaicensis*	Present	Common	Breeder	X
Red-winged blackbird	*Agelaius phoeniceus*	Present	Rare	Migratory	X
Rock pigeon[4]	*Columba livia*	Present	Common	Breeder	X
Rock wren	*Salpinctes obsoletus*	Present	Uncommon	Breeder	–
Rose-throated Becard	*Pachyramphus aglaiae*	Present	Occasional	Vagrant	–
Rough-legged Hawk	*Buteo lagopus*	Present	Occasional	Migratory	–
Ruby-crowned kinglet	*Regulus calendula*	Present	Common	Resident	X
Rufous hummingbird	*Selasphorus rufus*	Present	Rare	Migratory	–
Rufous-crowned sparrow	*Aimophila ruficeps*	Present	Uncommon	Breeder	X
Rufous-winged sparrow	*Peucaea carpalis*	Present	Common	Breeder	X
Sagebrush sparrow/Bell's sparrow[1]	*Artemisiospiza nevadensis/belli*	Unconfirmed	––	–	–
Savannah sparrow	*Passerculus sandwichensis*	Present	Rare	Migratory	X
Say's phoebe	*Sayornis saya*	Present	Common	Breeder	X
Scaled quail	*Callipepla squamata*	Unconfirmed	–	–	–
Scott's Oriole	*Icterus parisorum*	Present	Rare	Migratory	X
Sharp-shinned hawk	*Accipiter striatus*	Present	Rare	Migratory	–
Short-tailed hawk	*Buteo brachyurus*	Present	Occasional	Breeder	–
Snowy egret	*Egretta thula*	Present	Rare	Migratory	–
Song sparrow	*Melospiza melodia*	Present	Common	Breeder	X
Spotted sandpiper	*Actitis macularius*	Present	Rare	Migratory	–
Spotted towhee	*Pipilo maculatus*	Present	Rare	Migratory	X
Streak-backed oriole	*Icterus pustulatus*	Present	Occasional	Vagrant	–
Sulphur-bellied flycatcher	*Myiodynastes luteiventris*	Unconfirmed	–	–	–
Summer tanager	*Piranga rubra*	Present	Common	Breeder	X
Swainson's hawk	*Buteo swainsoni*	Present	Uncommon	Migratory	–
Swainson's thrush	*Catharus ustulatus*	Present	Rare	Migratory	X
Thick-billed kingbird	*Tyrannus crassirostris*	Present	Uncommon	Breeder	X
Townsend's solitaire	*Myadestes townsendi*	Present	Rare	Migratory	–
Townsend's warbler	*Setophaga townsendi*	Present	Rare	Migratory	X
Tree swallow	*Tachycineta bicolor*	Present	Uncommon	Migratory	X
Tropical kingbird	*Tyrannus melancholicus*	Present	Uncommon	Breeder	X
Turkey vulture	*Cathartes aura*	Present	Common	Resident	X
Varied bunting	*Passerina versicolor*	Present	Uncommon	Breeder	X
Vaux's swift	*Chaetura vauxi*	Present	Rare	Migratory	X
Verdin	*Auriparus flaviceps*	Present	Common	Breeder	X

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Table B-1 continued. ***Bird species list for Tumacácori NHP.***

Common Name	Scientific Name	Occurrence	Abundance	NPSpecies Tags	SODN Riparian Surveys
Vermilion flycatcher	*Pyrocephalus rubinus*	Present	Uncommon	Breeder	X
Vesper sparrow	*Pooecetes gramineus*	Present	Rare	Migratory	–
Violet-crowned hummingbird	*Amazilia violiceps*	Present	Occasional	Migratory	–
Violet-green swallow	*Tachycineta thalassina*	Present	Uncommon	Migratory	X
Virginia's warbler	*Oreothlypis virginiae*	Present	Uncommon	Migratory	–
Warbling vireo	*Vireo gilvus*	Present	Uncommon	Migratory	X
Western bluebird	*Sialia mexicana*	Unconfirmed	–	–	–
Western kingbird	*Tyrannus verticalis*	Present	Common	Breeder	X
Western meadowlark	*Sturnella neglecta*	Present	Rare	Resident	X
Western screech-owl	*Megascops kennicottii*	Present	Uncommon	Breeder	–
Western tanager	*Piranga ludoviciana*	Present	Uncommon	Migratory	X
Western wood-pewee	*Contopus sordidulus*	Present	Uncommon	Migratory	X
White-breasted nuthatch	*Sitta carolinensis*	Present	Uncommon	Breeder	X
White-crowned sparrow	*Zonotrichia leucophrys*	Present	Common	Resident	X
White-eared hummingbird	*Hylocharis leucotis*	–	–	–	X
White-faced ibis	*Plegadis chihi*	Present	Rare	Migratory	–
White-throated sparrow	*Zonotrichia albicollis*	Present	Occasional	Vagrant	–
White-throated swift	*Aeronautes saxatalis*	Present	Uncommon	Resident	–
White-winged dove	*Zenaida asiatica*	Present	Common	Breeder	X
Willow flycatcher[2]	*Empidonax traillii*	Probably Present	–	–	–
Wilson's snipe	*Gallinago delicata*	Present	Rare	Migratory	–
Wilson's warbler	*Cardellina pusilla*	Present	Uncommon	Migratory	X
Woodhouse's scrub-jay	*Aphelocoma californica*	Present	Occasional	Vagrant	–
Worm-eating warbler	*Helmitheros vermivorum*	Present	Occasional	Vagrant	–
Yellow warbler	*Setophaga petechia*	Present	Common	Breeder	–
Yellow-bellied flycatcher[3]	*Empidonax flaviventris*	Unconfirmed	–	–	–
Yellow-billed cuckoo	*Coccyzus americanus*	Present	Uncommon	Breeder	X
Yellow-breasted chat	*Icteria virens*	Present	Common	Breeder	X
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*	Present	Rare	Migratory	–
Yellow-rumped warbler	*Setophaga coronata*	Present	Common	Resident	X
Yellow-throated vireo	*Vireo flavifrons Vireo flavifrons*	Present	Rare	Migratory	X
Zone-tailed hawk	*Buteo albonotatus*	Present	Uncommon	Breeder	X

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NPS 311/156590, August 2019

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U.S. Department of the Interior

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