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Status of the Threatened Chiricahua Leopard Frog and Conservation Challenges in Sonora, Mexico, with Notes on Other Ranid Frogs and Non-native Predators

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***Abstract.*—In North America, ranid frogs (Ranidae) have experienced larger declines than any other amphibian family, particularly species native to the southwestern USA and adjacent Mexico; however, our knowledge of their conservation status and threats is limited in Mexico. We assessed the status of the federally listed as threatened (USA) Chiricahua Leopard Frog (*Lithobates chiricahuensis*) in Sonora, Mexico, based on a search of museum specimens, published records, unpublished accounts, and surveys from 2000–2016 of 84 sites within the geographical and elevational range of the species. We also provide information on occurrence of three other native ranid frog species encountered opportunistically during our surveys. The Chiricahua Leopard Frog is known in Sonora from only 20 historical (pre-2000) localities. Searches of three historical sites did not reveal any Chiricahua Leopard Frogs; however, we found it at three previously undocumented sites in 2016, all near Cananea. To our knowledge, these records are the first observations of Chiricahua Leopard Frogs in Sonora since 1998. Differences in conservation status between the USA and Sonora are likely due to differing magnitude and distribution of threats and a comparatively aggressive recovery program in the USA. For example, key non-native predators important in the decline of the Chiricahua Leopard Frog are much less widespread in Sonora compared to the southwestern USA, but there are fewer protections and recovery actions for the frog in Sonora than in the USA. Additional surveys for the Chiricahua Leopard Frog and other amphibians in Sonora should be a priority to fully assess threats and conservation status.**

Key Words.—amphibians; conservation; invasive species; *Lithobates chiricahuensis*; threatened species

Introduction

An estimated 42% of all extant amphibian species are threatened with extinction (International Union for the Conservation of Nature [IUCN] Red List 2016–3, amphibian analysis. Table 1. http://www.iucnredlist.org/initiatives/amphibians/analysis. [Accessed February 2017]). Causes of population declines and extinctions are not always clear, but habitat degradation and loss, climate change, introduced species, and emerging infectious diseases are important contributing factors (Green 2005; Halliday 2005; Whittaker et al. 2013; Kolby and Daszak 2016; Thompson et al. 2016). In the southwestern USA and northwestern Mexico, the Chiricahua Leopard Frog (*Lithobates chiricahuensis*) and other native frogs in the genus *Lithobates* have been adversely affected by a variety of introduced predators, habitat degradation, and chytridiomycosis, a skin disease caused by the fungus *Batrachochytrium dendrobatidis* (*Bd*; Bradley et al. 2002; Rosen and Schwalbe 2002; Hale et al. 2005; Rorabaugh and Lemos-Espinal 2016). All seven native ranid frog species in the southwestern U.S. have experienced population declines since the 1970s (Clarkson and Rorabaugh 1989; Sredl et al. 1997; Stuart et al. 2008; Lannoo 2005), and similar declines have been noted in northwestern Mexico (Hale et al. 2005; Stuart et al. 2008; Rorabaugh and Lemos-Espinal 2016). Although other native ranid frogs have suffered extensive population losses, the Chiricahua Leopard Frog is the only southwestern ranid listed on the U.S. Threatened and Endangered Species List (U.S. Fish and Wildlife Service [USFWS] 2002). It is also listed

Table 1. Herpetological museums queried for Chiricahua Leopard Frog (*Lithobates chiricahuensis*) collections.

Abbreviation	Full Name
AMNH	American Museum of Natural History
ASU	Arizona State University Herpetology Collection
BMNH	Bishop Museum of Natural History
BYU	Brigham Young University
BYUH	Monty L. Bean Life Science Museum
CAS	California Academy of Science, including Stanford University collections (SU)
CUMV	Cornell University Museum of Vertebrates
FLMNH	Florida Museum of Natural History
FMNH	Field Museum of Natural History
KU	University of Kansas Natural History Museum
INHS	Illinois Natural History Survey
LACM	Los Angeles County Museum
LSUMZ	Louisiana State University Museum of Natural History
MCZ	Harvard University Museum of Comparative Zoology
MSUM	Michigan State University Museum
MVZ	Museum of Vertebrate Zoology
PSM	Slater Museum of Natural History
ROM	Royal Ontario Museum
SDNHM	San Diego Natural History Museum
TNHC	University of Texas at Austin
UAZ	University of Arizona Herpetology Collection
UCM	University of Colorado Museum at Boulder
UIMNH	University of Illinois Museum of Natural History
UMMZ	University of Michigan Museum of Zoology
UNAM	Universidad Nacional Autónoma de México
USNM	National Museum of Natural History
UTA	University of Texas at Arlington
UTEP	University of Texas at El Paso

as amenazada (= threatened) on the Lista de Especies en Riesgo of Mexico (Secretaría de Medio Ambiente y Recursos Naturales [SEMARNAT] 2010).

The Chiricahua Leopard Frog faces several additional challenges, some of which are symptomatic of arid and dynamic habitats. For example, disruption of metapopulation dynamics due to drought and reduced connectivity may result in small populations that are more susceptible to demographic or other forms of stochasticity (USFWS 2007; Witte et al. 2008). Isolated populations at high elevation and frogs associated with non-native Virile Crayfish (*Orconectes virilis*) may be particularly threatened (Witte et al. 2008).

Although many surveys for Chiricahua Leopard Frogs are conducted each year in Arizona and New Mexico, the status of the species in Mexico is poorly known (USFWS 2011). Lemos-Espinal et al. (2015) listed only 20 historical localities for the Chiricahua Leopard Frog in Sonora and 35 for Chihuahua; a few additional localities are known from Durango (Platz and Mecham 1984, Streicher et al. 2012). Despite an emphasis in the Chiricahua Leopard Frog Recovery Plan to work with Mexican partners to determine the distribution and population status of the Chiricahua Leopard Frog (USFWS 2007), only one historical locality in Sonora has been visited recently (2009, in the Sierra Los Ajos, site 8 or 11, Appendix) and no frogs were found there (USFWS 2011). Herein, we discuss the status of the Chiricahua Leopard Frog in Sonora based on historical localities (pre-2000) and recent surveys (2000–2016), as well as an assessment of threats and recovery actions with comparisons to Arizona and New Mexico.

Materials and Methods

The Chiricahua Leopard Frog is a large (< 135 mm snout-vent length), spotted frog (Fig. 1) known

Figure 1. Chiricahua Leopard Frog (*Lithobates chiricahuensis*) at site 3, El Barrilito, near Cananea, Mexico, 25 August 2016. (Photographed by James Rorabaugh).

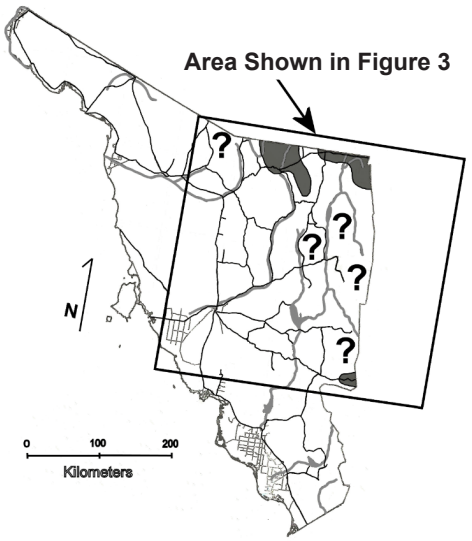

Figure 2. Distribution of the Chiricahua Leopard Frog (*Lithobates chiricahuensis*) in Sonora, Mexico (shaded areas) with inset showing area displayed in Figure 3. Roads are indicated by dark lines and rivers by thick gray lines. Areas of suitable habitat within the range of the species, but for which no records exist, are indicated by "?".

from central and southeastern Arizona, west-central and southwestern New Mexico, and south in Mexico through the Sierra Madre Occidental and adjacent areas to at least central Durango at elevations over 1,000 m (Platz and Mecham 1984; Rorabaugh and Sredl 2014). It inhabits a variety of wetlands, including beaver ponds, rivers, ciénegas, cattle tanks, and other permanent or nearly permanent aquatic sites (Sredl and Jennings 2005). We queried 28 herpetological collections (Table 1) and VertNet (http://portal.vertnet.org [Accessed March 2017]) for Chiricahua Leopard Frog records. Ranid records in the Arizona State University (ASU) collection from Sonora were catalogued only as *Rana* sp. or as the Northern Leopard Frog ("*Rana pipiens*"), so JCR visited the museum and identified Chiricahua Leopard Frogs from their 178 Sonoran ranid specimens. We also queried specific records from the University of Colorado Museum at Boulder and the University of Michigan Museum of Zoology and we examined them with museum staff. Further, we contacted other individuals working in eastern Sonora and searched literature on the herpetofauna of the area for records or mention of the species.

From 2000 through 2016, we conducted surveys for ranid frogs at sites within the published Chiricahua Leopard Frog range in Sonora that we define as the sky island region and Sierra Madre Occidental, which spans the landscape from the Arizona-Sonora border in northeastern Sonora south to the Yécora area (Fig. 2; Rorabaugh and Lemos-Espinal 2016). We visited 84 sites that were ≥ 800 m in elevation and included suitable habitat (Fig. 3). We conducted visual encounter surveys that followed protocols in Appendix E of the Chiricahua Leopard Frog Recovery Plan (USFWS 2007), although at sites 45, 48, 49, 53, 55, 58, 59, and 63 (Appendix), we found ranid frogs opportunistically outside of formal surveys. We conducted surveys primarily during the daytime from April through October. Most surveys during 2015–2016 from Cananea north to the Arizona border and west to the Río Santa Cruz included seining of ponds with a 9 × 2.4–m bag seine. We identified other native ranids based on morphological criteria, call types, and distributional information in Frost and Bagnara (1976) and Rorabaugh and Lemos-Espinal (2016). Despite confidence in our identifications, we acknowledge that differentiating between Lowland Leopard Frogs and Northwest Mexico Leopard Frogs (*L. magnaocularis*) in the field without genetic analysis can be problematic. In addition to noting ranid frogs, we also recorded observations of fishes, Virile Crayfish, and other amphibians.

Results

Historical localities.—Our search of museum records identified 20 Chiricahua Leopard Frog localities in Sonora where the species was collected from 1946 to 1986 (sites 6–25; Fig. 3; Appendix). Two specimens (LACM 91461 and 91462 from sites 15 and 16) had nonsensical locality data that could not be plotted with any accuracy and are not included. One of us (JCR) determined on examination that a "*Rana chiricahuensis*" specimen (UCM 65687) collected in 2003 from "Between Guisamopa and Cajon de Onapa" (site 58, elevation 597 m) was a Northwest Mexico Leopard Frog based on a reticulate thigh pattern and lateral orientation of the eyes. Our examination of "*Rana* sp." and "*Rana pipiens*" specimens from Sonora in the ASU collection resulted in addition of one Chiricahua Leopard Frog locality (site 23, ASU 20001–20014). Specimens UMMZ 78342,

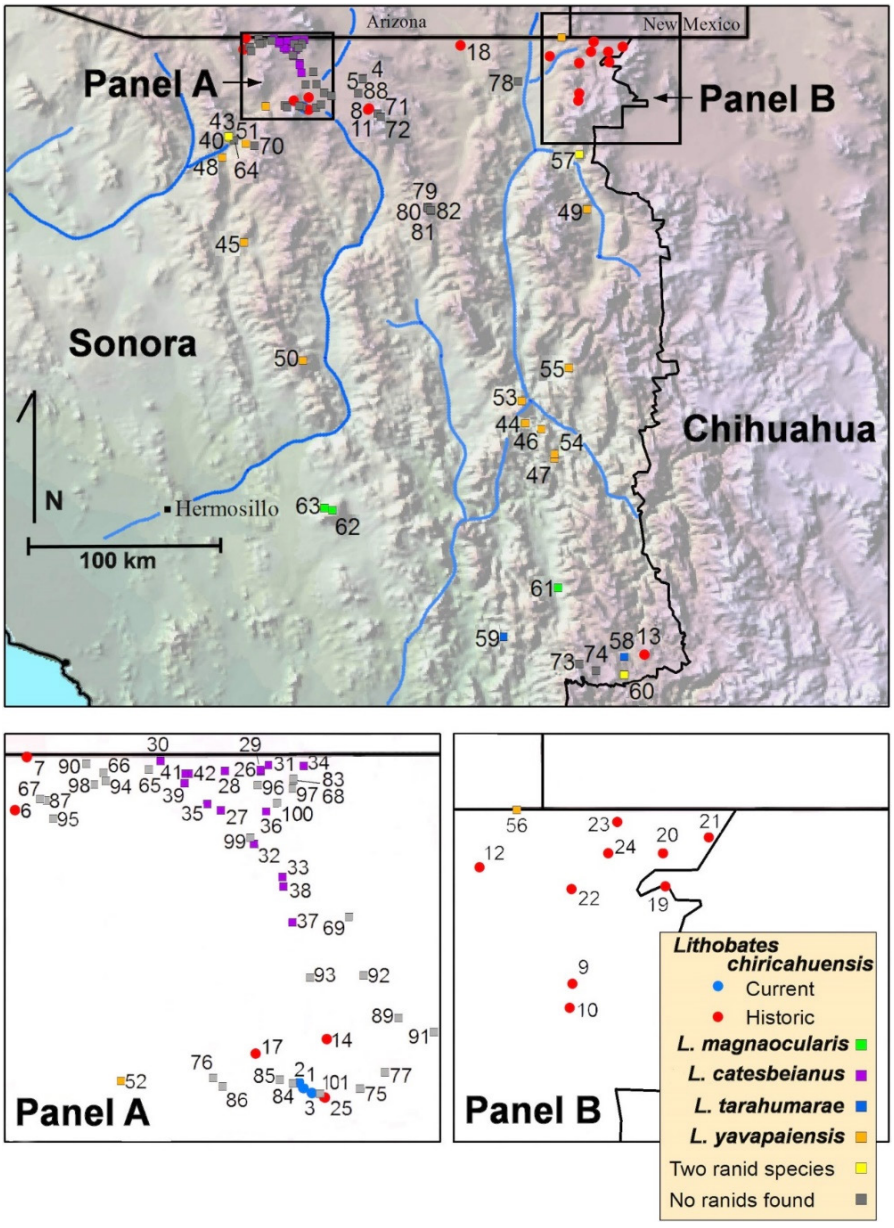

Figure 3. Localities for ranid frogs in Sonora, Mexico. Chiricahua Leopard Frog (*Lithobates chiricahuensis*: red circles = historic, blue circles = current). Yellow squares indicate that two ranid species were observed (43-Lowland Leopard Frog, *L. yavapaiensis*, + American Bullfrog *L. catesbeianus*; 57-*L. yavapaiensis* + Tarahumara Frog, *L. tarahumarae*; 60-Northwest Mexico Leopard Frog, *L. magnaocularis* + *L. tarahumarae*). See legend on figure for other color designations.

78344–78346, and 78349–78251 labeled as "*Rana pipiens*" and collected by Berry Campbell in 1935 from the Sierra El Tigre, between Esqueda and the Sierra El Tigre, and Pilares (in the Sierra Nacozari) appeared to be Lowland Leopard Frogs (Gregory Schneider, pers. comm.). In July 1998, Andrew Holycross (pers. comm.) observed a leopard frog in upper Cajon Bonito, Sierra San Luis (site 12), that he concluded was a Chiricahua Leopard Frog. We consider it a reliable sighting, and it is the most recent record prior to our surveys. Confirmed historical localities range from the Río Santa Cruz and the Cananea region eastward to include the Sierra Los Ajos, the Río Agua Prieta, numerous sites in the Sierra San Luis complex, and a site near Yécora in southeastern Sonora. Sites that could be plotted with accuracy ranged from 1,148 to 1,967 m in elevation and occurred in high valleys or mountains vegetated with Plains Grassland and possibly Semi-desert Grassland, as well as Oak Woodland and Pine-oak Woodland (Brown 1982; Fig. 3).

Field surveys.—Our field surveys identified Chiricahua Leopard Frogs at three new localities in Sonora. We seined leopard frog tadpoles at site 1 and observed a leopard frog egg mass at site 2. Neither could be identified to species based on visual inspection. As part of another project, analysis of environmental DNA (eDNA) samples we collected from these sites confirmed that tadpoles and the egg mass were Chiricahua Leopard Frogs (Caren Goldberg, pers. comm.). We found a single adult female Chiricahua Leopard Frog observed at El Barrilito (site 3, Fig. 1), a stream that was apparently highly polluted with sewage and possibly mining waste, based on the smell and appearance of the water. We also heard plops without accompanying "eep" calls (leopard frogs do not "eep," whereas American Bullfrogs (*Lithobates catesbeianus*) often do [Rorabaugh and Lemos-Espinal 2016]) along an agricultural ditch in a reach of El Barrilito (site 102) that we suspect were from Chiricahua Leopard Frogs, but because identity was not confirmed, that site is not included in Figure 3 as a Chiricahua Leopard Frog positive site. All four of these sites are within 3.5 km NNW of Cananea at elevations of 1,560–1,601 m at the base of the Sierra Elenita in an area of grassland with scattered evergreen oaks. We visited only three (sites 8, 11, 21) of the 20 historical Chiricahua Leopard Frog localities, although only one of those sites had precise locality information (site 21; the other two were difficult to locate). We found no ranids at those sites.

We found Lowland Leopard Frogs at 16 sites (40, 43–57), from just south of the Mexico-USA border south to the Northern Jaguar Reserve, about 222 km south of the international border. We found Northwest Mexico Leopard Frogs at four sites (60–63): two in the Sierra Mazatán, one near Yécora, and one at Cañón Onapa, 247–336 km south of the international border. We found Tarahumara Frogs (*Lithobates tarahumarae*) at four sites (57–60), 61–336 km south of the international border. The Tarahumara Frog was the only native ranid we did not find in cattle tanks. The other four species occurred in both cattle tanks and streams or other more natural aquatic sites. Only two sites supported more than one native ranid: we found Lowland Leopard Frogs with Tarahumara Frogs at site 57, and Northwest Mexico Leopard Frogs with Tarahumara Frogs at site 60. We found no ranids at 42 surveyed sites (4, 5, 21, 64–102; Fig. 3; Appendix).

Non-native predators.—We found American Bullfrogs at 16 sites (26–43; Fig. 3), including localities in the Ríos Magdalena, Santa Cruz, and San Pedro drainages. Also, William Radke (pers. comm.) informed us of American Bullfrogs near the Mexico-USA border in the Río San Bernardino drainage, a tributary to the Ríos Bavispe and Yaqui (this site is not plotted on Figs. 3 or 4). We documented multiple non-native species at sites 40 and 43, including American Bullfrog, Virile Crayfish, Green Sunfish (*Lepomis cyanellus*), Mosquitofish (*Gambusia affinis*), and Largemouth Bass (*Micropterus salmoides*). We also found American Bullfrog, Virile Crayfish, Green Sunfish, and Black Bullhead (*Ameiurus melas*) at sites from Cananea north to the Mexico-USA border (Fig. 4). We found the non-native Spiny Softshell (*Apalone spinifera*) at site 69, 17.9 km south of the Mexico-USA border (Rorabaugh and King 2013). None of our non-native predator localities are more than 53 km south of the Mexico–USA border.

We also found numerous species of native amphibians other than ranids, and some native fishes, during our surveys. Most of those records can be found in the Madrean Discovery Expedition (MDE), formerly Madrean Archipelago Biodiversity Assessment (MABA), database (http://madrean.org/symbfauna/index.php). Also see Hossack et al. (2016).

Discussion

Status of the Chiricahua Leopard Frog in Sonora.—To our knowledge, our 2016 discovery of Chiricahua Leopard Frogs at three sites near Cananea are the first detections of this species in Sonora since 1998. We confirmed breeding at sites 1 and 2, whereas we found only a single adult frog at site 3. The three sites (1–3), plus a fourth possible locality (site 102) are all within 2.9 km of each other, which is well within the dispersal capability of this frog, so these sites may operate as a metapopulation (USFWS 2007). Our surveys of the Cananea region were not comprehensive, and it is quite possible that other occupied sites occur in the area.

Several lines of evidence suggest that if ranids were present at a surveyed site, we would have detected them most of the time. Chandler et al. (2015) calculated a detection probability of 0.69 (95% CI: 0.60–0.78) for Chiricahua Leopard Frog in the Altar Valley, Arizona, USA, during night surveys in June 2007–2012. After three surveys, detection probability exceeded 0.97. Chiricahua Leopard Frogs are generally easier to detect at night because of their eye shine and increased approachability, and in June frogs are typically concentrated into remaining pools before the onset of the summer rainy season. Hence, detectability with the methodologies of Chandler et al. should be relatively high. We conducted our surveys primarily during the day and from April through October; hence, the results of Chandler et al. (2015) may not be applicable to our work. In Arizona, Howland et al. (1997) reported that, if present, Lowland Leopard Frogs were detected in 93% of visual encounter surveys. Those surveys were similar in timing and methods to those conducted by us. However, our use of a 9-m bag seine at some sites

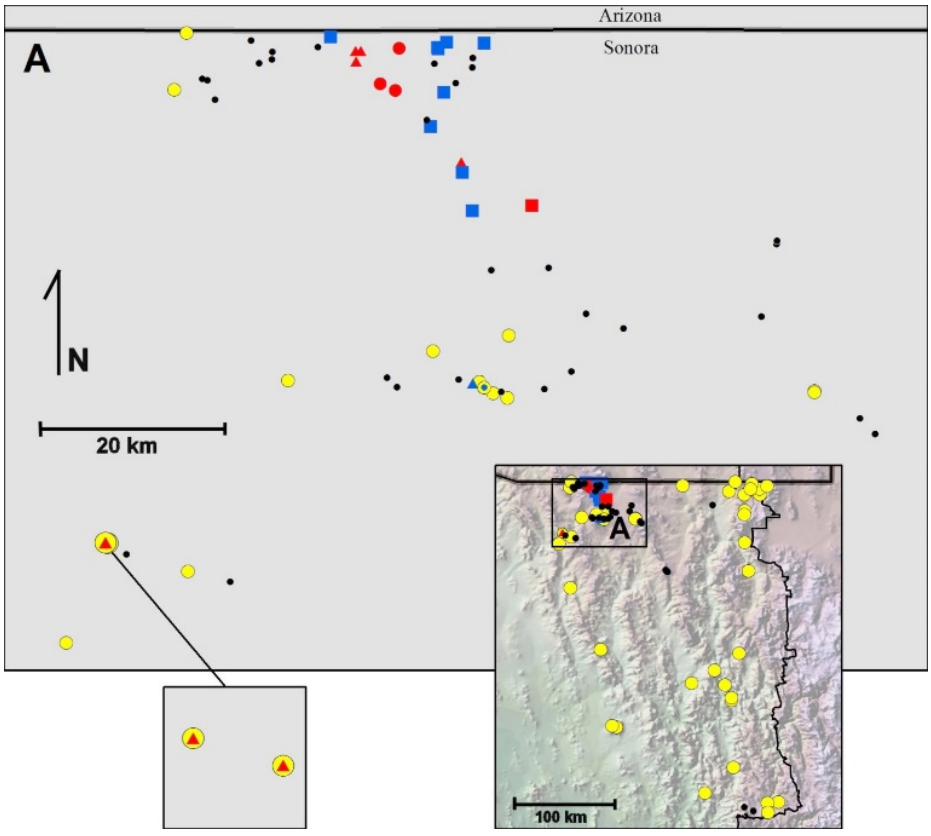

Figure 4. Localities of non-native species relative to ranid frogs. Black circles indicate localities with no ranid frogs, yellow circles indicate native ranid species (Chiricahua Leopard Frog, *Lithobates chiricahuensis*, Lowland Leopard Frog, *L. yavapaiensis*, Northwest Mexico Leopard Frog, *L. magnaocularis*, Tarahumara Frog, *L. tarahumarae*). Co-occurence of native ranids with non-native species is indicated by a symbol superimposed over the yellow circle: Non-native fish species = blue circle; non-native fish + *L. catesbeianus* = red triangle; non-native fish + *L. catesbeianus* +Virile Crayfish (*Orconectes virilis*) = red circle. Non-natives occurring in sites without native ranids: *L. catesbeianus* = blue square; crayfish = blue triangle; Spiny Softshell (*Apalone spinifera*) = red square; non-native fish + *L. catesbeianus* = red triangle; non-native fish + *L. catesbeianus* + Virile Crayfish = red circle.

enhanced our ability to detect ranid frogs beyond using only the visual encounter survey methods. In addition, we surveyed some sites, such as at Ranchos Los Fresnos and El Aribabi, numerous times over several years, increasing the likelihood of finding ranids if they were present (Chandler et al. 2015; Appendix). As well, the sites we sampled were often structurally fairly simple. Cattle tanks rarely had much vegetation, so if frogs were not submerged, there was little opportunity for them to hide. Similarly, most streams we sampled were small with relatively little escape cover. Eliminating the eight sites where we found ranid frogs opportunistically outside of formal surveys, we found them at 48% (34 of 76) of sites surveyed according to protocols in USFWS (2007), which represents a minimum detection probability for all ranid frogs combined.

Based on records in adjacent areas of Arizona and Chihuahua (Platz and Mecham 1984; Rorabaugh and Sredl 2014; Lemos-Espinal et al. 2015), it is likely that Chiricahua Leopard Frogs also occur or occurred in other areas not indicated by historical localities in Figure 3. These sources suggest the distribution of the Chiricahua Leopard Frog likely extends or extended westward through the Mexico-USA border region possibly to El Sasabe, and in the Sierra Madre Occidental along the Sonora-Chihuahua border north and perhaps south of Yécora. We have not surveyed these areas, and there are relatively few amphibian museum records from them. Similarly, the species might occur or have occurred in some of the larger sky island mountain ranges in northeastern Sonora, such as the Sierras Azul, El Tigre, Nacozari, La Madera, or others from which no Chiricahua Leopard Frog records or collections exist. Until recently, high elevation areas in the mountains of northeastern Sonora were poorly surveyed for ranid frogs and other amphibians or reptiles. From 2009 to 2017, several of these sky island mountains were surveyed for plants and animals during short-term, intensive bio-blitz expeditions led by Sky Island Alliance and Greater Good (e.g., Van Devender et al. 2013). These surveys

were often high in the mountains, but at these elevations there are typically few cattle tanks or streams adequate to support ranid frogs. Few ranids and no Chiricahua Leopard Frogs were found during these expeditions, possibly because of the paucity of suitable habitat. Searching lower elevation streams and ponds, but still above 800 m, may be more productive.

Several other scientists have surveyed for ranid frogs in Sonora without finding Chiricahua Leopard Frogs. For example, in the Yécora region and along Highway 16 in eastern Sonora, Enderson et al. (2014) found 20 species of amphibians, including Northwest Mexico Leopard Frogs and Tarahumara Frogs, but they did not encounter Chiricahua Leopard Frogs. Rosen and Melendez (2010) visited 28 aquatic sites in Sonora and found Lowland and Northwest Mexico Leopard Frogs and Tarahumara Frogs but did not find Chiricahua Leopard Frogs, although many of the sites they visited were lower in elevation or not within the presumed geographical range of the Chiricahua Leopard Frog. Rorabaugh et al. (2011) found Lowland and Northwest Mexico leopard frogs and Tarahumara Frogs at the Northern Jaguar Reserve in east-central Sonora, but no other ranids. From 1981 to 1999, Hale et al. (1995, 2005) found Tarahumara Frogs, Lowland Leopard Frogs, and Northwest Mexico Leopard Frogs in numerous wet arroyos and canyons, mostly in the lower to mid-elevations of many sky islands and the Sierra Madre Occidental in Sonora, but found Chiricahua Leopard Frogs at only four sites (8–11), and all were during 1982–1985.

Our finding of Chiricahua Leopard Frogs at only three (possibly four) sites, all in the Cananea area, detection of four other ranid species at numerous sites throughout eastern Sonora, and the lack of recent (post-1998) Chiricahua Leopard Frog observations by other workers suggest a decline in occupied sites and distribution of this threatened frog. However, we only visited three of the 20 Chiricahua Leopard Frog historical localities, and our surveys did not extend to some areas where the species may occur. As a result, additional survey work, including visiting more of the historical localities and other areas is needed to better define the conservation status of the Chiricahua Leopard Frog in Sonora.

USA-Sonora comparisons of threats: non-native predators.—Throughout the range of the Chiricahua Leopard Frog in Arizona and New Mexico, non-native predacious fishes, American Bullfrogs, and crayfishes are widespread in a variety of aquatic habitats (Degenhardt et al. 1996; Minckley and Marsh 2009; Brennan and Holycross 2006; Witte et al. 2008; Inman et al., unpubl. report), and have contributed to declines and extirpations of a number of native wetland vertebrates, including the Chiricahua Leopard Frog (Minckley 1991; Rosen and Schwalbe 2002; Hossack et al. 2017). Chiricahua Leopard Frogs are not often found with non-native fishes, Virile Crayfish, or American Bullfrogs, and can be eliminated by these predators (Sredl and Howland 1995; Rosen and Schwalbe 2002; Witte et al. 2008). Notably, site 1 contained both Chiricahua Leopard Frog tadpoles and small Green Sunfish. However, a thick mat of carophytic green algae (*Chara* sp.) covered about half the pond and likely provided sufficient cover for the tadpoles to escape predation. We found a single Virile Crayfish at site 84, which is 1.1 km from site 1, 0.6 km from site 2, and 2.1 km from site 3 (the three sites with Chiricahua Leopard Frogs). A local individual we talked to reported seeing langostino (= shrimp) at site 3, which may have been Virile Crayfish, although we observed none there. Virile Crayfish move considerable distances; in a study in Arizona, 1.4% of individuals moved nearly 4 km among cattle tanks (Blomquist 2003). Thus, all three Chiricahua Leopard Frog localities we identified in 2016 are at risk of invasion by Virile Crayfish, if they are not already present.

Throughout our survey area, we found non-native predators, including American Bullfrogs, Virile Crayfish, four species of non-native fish, and Spiny Softshell at numerous sites in the Mexico-USA border region. Importantly, we encountered no non-native predators at aquatic sites farther south than Cananea in the Río San Pedro drainage (site 1, 37 km south of the Mexico-USA border) and Rancho El Aribabi in the Río Magdalena drainage (site 43, 53 km south of the Mexico-USA border). We did not find non-native fishes at the Saracachi Ciénega (site 45, 107 km south of the Mexico-USA border) in October 2010, and neither did Rosen and Melendez (2010) in 2005; however, Green Sunfish and Largemouth Bass were present in April 2011 (MDE database, son-trv-2663, son-trv-2662). Non-native fishes occur in central and southern Sonora, but mostly in large river systems or reservoirs below the elevational range of the Chiricahua Leopard Frog (Minckley and Marsh 2009; Rosen and Melendez 2010), places that we did not sample. American Bullfrogs also occur in southwestern Sonora at relatively low elevations (Rorabaugh and Lemos-Espinal 2016). Other than the sites where we found them, the only other non-native crayfish records from eastern Sonora of which we are aware are Virile Crayfish from the Río Agua Prieta in the town of Agua Prieta, immediately south of the Mexico-USA border (mde-3509), and the Río San Pedro within 5 km of the border (mde-9957).

It is likely that non-natives in the Río San Pedro basin of Sonora, which include all of the species noted above and in Figure 2, have arrived via dispersal from contiguous reaches of the San Pedro River in Arizona (Rosen 2009; Stefferud et al. 2009). Similarly, some non-native fishes and American Bullfrogs have likely entered the Río Yaqui system via its headwaters in

Arizona. Those headwaters are limited in size, however, and San Bernardino National Wildlife Refuge just north of the Mexico-USA border, which actively manages for native fishes, likely provides a buffer against some non-native introductions. Non-native species, particularly fishes and Virile Crayfish in the Río Cocospera (sites 40, 43), and fishes in the Saracachi Ciénega (site 45) are likely the result of human introduction because neither system is connected with drainages or other waters in the USA. In addition, we suspect that the presence of Green Sunfish at site 1, an isolated pond elevated above the Río San Pedro, is also a result of human introduction. These observations suggest that non-natives in Sonora are moving on their own southward from established populations in Arizona, but are also being moved by people.

Based on the presence of 42 non-native fish species from the Gila River system of Arizona and New Mexico and 22 species from the Río Yaqui, Unmack and Fagan (2004) estimated the Yaqui fish assemblage was 40–50 y behind the Gila in terms of invasions of non-native species. They attributed that time lag to the isolated nature of the Río Yaqui region, a slow pace of water development projects in Sonora, and lack of a government-sponsored program of stocking fish. Unlike southern Arizona, where there are a number of popular fishing lakes with associated shops selling bait and fishing gear, we are unaware of any similar commercial or sport fishing outlets in eastern Sonora. We never encountered fisherman at the sites we surveyed for frogs. However, we occasionally saw fisherman at lower elevations along the Río Yaqui/Bavispe, and we are aware of fishing at Presa Comiquito, a reservoir downstream of sites 40 and 43 on the Río Cocospera, which is likely the source of non-native fishes in that river system. Thus, there probably is little motivation to establish non-native fish populations in eastern Sonora. From conversations with local individuals, few want to eat frogs, so human-mediated movement of American Bullfrogs around on the landscape is also unlikely.

Despite less anthropogenic influence than in Arizona and New Mexico, non-natives are well-represented in eastern Sonora. Twenty-two species of non-native fishes occur in the Río Yaqui, the largest river system in Sonora. In addition, American Bullfrogs occur at the headwaters of the Río Yaqui in Arizona and Sonora and in the lower reaches in Sonora. American Bullfrogs and Virile Crayfish also occur in the Río Papigochic, a tributary of the Río Yaqui in Chihuahua (James Rorabaugh, pers. obs.). Thus, these two non-native predators appear well-positioned to invade most or all of the Río Yaqui and its tributaries (Rosen and Melendez 2010; Rorabaugh and Lemos-Espinal 2016). This situation does not bode well for the future of native ranid frogs and other vulnerable aquatic fauna in the Río Yaqui basin.

U.S.-Sonora comparisons of threats: habitat loss and degradation.—Habitat destruction and alteration is a major cause of amphibian decline (Chanson et al. 2004; Collins et al. 2005; Halliday 2005), and it has played a role in the decline of the Chiricahua Leopard Frog (Sredl and Howland 1995; Sredl and Jennings 2005). It is also an important factor at the three sites where we found Chiricahua Leopard Frogs in Sonora. The two breeding sites are in imminent danger of destruction because they are in an area of active expansion of a working copper mine (Guillermo Molina-Padilla, pers. comm.). Site 3, where we found an adult Chiricahua Leopard Frog, is an apparently polluted stream.

Construction of impoundments to supply water for livestock is generally considered beneficial for the Chiricahua Leopard Frog because it has created many habitats where the species can breed and use for dispersal (Rosen and Schwalbe 1998; Chandler et al. 2015), and these tanks are invaded by non-natives to a lesser degree than natural habitats (Sredl and Saylor 1998). Because we did not visit most Chiricahua Leopard Frog historical localities, we do not know how many of them are tanks created or modified for livestock. However, site 9 is described as a cattle pond in the museum catalog, and sites 14 and 15 are described as ponds and are likely cattle tanks. Of the 84 sites that we surveyed, 43 were impoundments we assume were constructed primarily as cattle tanks. Ten were occupied by native ranids (23%), two by Chiricahua Leopard Frogs (5%), and eight by American Bullfrogs (14%). This compares to 15 of 41 (37%) streams and other more natural sites that supported native ranids and 12 of 41 (29%) that supported American Bullfrogs. The ratio of sites occupied by American Bullfrogs versus native ranids was the same for cattle tanks (8/10) and streams or other more natural sites (12/15).

Catastrophic wildfire can have profound effects on amphibian habitat and populations in the southwestern U.S. (Hossack and Pilliod 2011), and in some areas, these fires are expected to increase as a result of climate change (Westerling et al. 2006). Chiricahua Leopard Frogs were collected in Cañon Diablo in the Sierra San Luis (site 21) in May 1986, but were not found by us in 2002 (Appendix). A catastrophic wildfire swept through site 21 in June-July 1989 and subsequent rains triggered severe erosion of slopes and incisement of canyon bottoms (David Barker, unpubl. report). We suspect these events may have eliminated resident Chiricahua Leopard Frogs. In May 2002, the canyon bottom was still loaded with gravel and rocks and there were only a few small pools capable of supporting ranid frogs. Due

to removal of fine fuels by livestock grazing followed by effective fire suppression, low intensity surface fires disappeared in the mountains of southeastern Arizona and southwestern New Mexico beginning in 1870–1900, but continued unaltered in the Sierra Los Ajos and other mountains in northeastern Sonora where effective fire suppression has never occurred and livestock grazing in the higher elevations is light to moderate (Swetnam and Baisan 1996). Loss of frequent surface fires allowed growth of ladder fuels, facilitating stand-replacing catastrophic fires in the USA but not Sonora. As a result, despite what happened at site 21, catastrophic fires in the mountains of eastern Sonora are rare compared to the southwestern USA and fire poses less of a threat to ranid frogs there.

USA-Sonora comparisons of threats: disease.—We did not include disease monitoring in our surveys; however, Chiricahua Leopard Frogs are susceptible to chytridiomycosis, which is widespread within the range of the species in the USA and it is a challenge for recovery in some areas (Bradley et al. 2002; USFWS 2007). Chiricahua Leopard Frog tadpoles at site 1 appeared normal. The one frog found at site 3, an adult female, appeared healthy except for a reddening of the skin on the lateral surface of the right hind leg, which is seen in Figure 1. Other ranid frogs we found were generally healthy, although we encountered a dead American Bullfrog adult at site 38. Zamora-Bárcenas et al. (2012) noted a large American Bullfrog tadpole at site 39 with severe loss of pigment in the mouthparts, which can be a symptom of *Bd* infections (Knapp and Morgan 2006).

Through histological examinations, Hale et al. (2005) demonstrated that *Bd* is widespread in eastern Sonora from the Sierra San Luis in the northeast south to almost the Sinaloa border, and often at quite remote sites. Tarahumara Frogs, Lowland Leopard Frogs, Northwest Mexico Leopard Frogs, and White-striped Frog (*Lithobates pustulosa*) were infected with the pathogen, and Tarahumara Frogs found during a die-off in a remote arroyo of the Sierra El Tigre showed symptoms of chytridiomycosis and were *Bd*-positive. The earliest detection of *Bd* in Sonora via histology was from Tarahumara Frogs collected at two sites in 1982 (Hale et al. 2005). However, frogs from the Sierra El Tigre site had apparent symptoms of chytridiomycosis in 1981. The authors did not examine any Chiricahua Leopard Frogs for presence of *Bd*. Others have noted die-offs of ranid frogs that may have been caused by disease, including at the Northern Jaguar Reserve in 2009, 2010, and 2014 (Tarahumara Frogs and Lowland Leopard Frogs; James Rorabaugh and Juan Carlos-Bravo, pers. obs.) and in an arroyo near Rosario de Tesopaco in southeastern Sonora (Northwest Mexico Leopard Frogs; Zamora-Bárcenas et al. 2012). Taken together, these findings suggest that, similar to the southwestern USA, *Bd* occurs broadly across the range of the Chiricahua Leopard Frog in Sonora, but how or if populations of the frog have been affected in Mexico is unknown. Hale et al. (2005) suggest that warmer temperatures at sites in Sonora as compared to Arizona may mitigate the effects of chytridiomycosis on Tarahumara Frogs. Die-offs of leopard frogs in Arizona associated with *Bd* typically occur in the winter when water temperatures are low (Sredl and Caldwell 2000; Bradley et al. 2002; Forrest and Schlaepfer 2011). Thus, it is possible that the disease is less of a factor for Chiricahua Leopard Frogs and other ranids at the lower latitudes in Sonora where winter temperatures are warmer.

Differing levels of recovery actions.—Another important difference in the conservation status of the Chiricahua Leopard Frog between Sonora and the USA is the level of recovery actions. In Arizona and New Mexico, population monitoring, control of non-native predators, habitat enhancement and creation, and population augmentation and re-establishment have been aggressively pursued since the 1990s (Rorabaugh et al. 2008; Sredl et al. 2011; USFWS 2011). As of 2011, Chiricahua Leopard Frogs had been introduced to 30 sites in the USA, and were still present at 22 of them (USFWS 2011). In southern Arizona, introductions have re-established frogs in the Chiricahua Mountains and Buenos Aires National Wildlife Refuge, places from which Chiricahua Leopard Frogs had been extirpated, and the species would likely be absent from the Huachuca Mountains but for introductions and other intensive management (USFWS 2011; Frederick et al. 2013; Howell et al. 2016). No such recovery actions are occurring in Sonora.

Effective recovery of the Chiricahua Leopard Frog includes threat abatement and often population establishment, but those activities must address unique circumstances at specific sites (USFWS 2007). At this point, not enough is known of the status of the frog in Sonora or elsewhere in Mexico to identify specific recovery sites or actions. Recovery actions 11.1 and 11.2 in the recovery plan for the species call for working with Mexican partners to determine the distribution and population status of the Chiricahua Leopard Frog, and to develop partnerships between the USA and Mexico to implement recovery actions (USFWS 2007). Our work represents an initial step in that process.

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The authors and collaborators. From left to right: Brent Sigafus, Daniel Toyos Martínez, Erin Muths, David Hurtado Felix, Thierry Chambert, Aline Estrella Zamora, Blake Hossack, Jim Rorabaugh, and Guillermo Molina Padilla. Parque Tamosura, Cananea, Sonora, Mexico. (Photographed by Brent Sigafus). Inset, upper right: Julio Lemos-Espinal. (Photographed by Susy Sanoja Sarabia).

Appendix

Sites visited and museum specimen localities, including locality (site name, coordinates in WGS84), museum number (see Table 1 for museum abbreviations; capitalized) or Madrean Discovery Expedition (MDE)/ Madrean Archipelago Biodiversity Assessment (MABA) number (if any; lower case), and month and year visited. Sites were visited once, unless otherwise indicated.

Site **1)** Cattle pond at Mina La Catalina, 2.9 km (by air) WNW of Cananea, 30.99997°N, 110.31264°W, May 2016 **2)** Cattle pond, Mina La Catalina, 3.5 km (by air) WNW of Cananea, 31.00524°N, 110.31653°W, May 2016 **3)** Arroyo El Barrilito, NW side of Cananea, 30.9948°N, 110.30378°W, Aug 2016 **4)** Large cattle tank, Villaverde, 32.7 km NE Cananea, 31.143216°N, 109.99573°W, May 2016 **5)** Overflow of large cattle tank, Villaverde, 32.7 km NE Cananea, 31.142762°N, 110.000306°W, May 2016 **6)** Rio Santa Cruz, 6.4 km S international border near Lochiel, UMMZ 105836, Apr 1950 **7)** Santa Cruz River near Lochiel, USNM 19862-19866, no date **8)** Cañon Evans, Sierra Los Ajos, downstream of where road enters, 20 mi ESE Cananea, UAZ 44732, Jun 1982, Oct 2009? **9)** El Yo (cattle tank) on ridge W of Cajon Bonito, Sierra Pan Duro, UAZ 46001, May 1985 **10)** El Represito, Arroyo Represito, Sierra Pan Duro, UAZ 46002, May 1985 **11)** Cañon Evans, Sierra Los Ajos, ca. 16 mi (by road) SE Hwy 2, UAZ 46028, Jun 1982, Oct 2009? **12)** Cajon Bonito, 6 mi S AZ/Sonora border, KU 37717, May 1982, Jul 1998 **13)** 18 km W Sonora/Chihuahua border on road to Yecora, KU 194589, May 1982 **14)** 4 mi N Cananea in pond, LACM 91446-7, Apr 1966 **15)** 34.1 mi E Imuris in pond, 11 mi NW, LACM 91461, Apr 1966, **16)** 5 mi NW Cananca (Cananea?), 11 mi NW Cananca, LACM 91462, Apr 1966 **17)** 5 mi NW Cananca (Cananea?), LACM 91463, Apr 1966 **18)** Rio de Agua Prieta, edge of town of Agua Prieta, LACM 91587-9, Jul 1965 **19)** Cañon Chimineas, Road to Rancho San Antonio, UTA 20310, Jul 1986 **20)** Rancho Nuevo Agua Blanca, 32 km W, 5 mi S of Antelope Wells, NM, UTA 20485-511, Aug 1986 **21)** Cañon Diablo, Sierra San Luis, UTA 20292–5, 20297, 20298, May 1986, May 2002 **22)** Rancho Chiltipin, Sierra San Luis, UTA 20348, Jul 1986 **23)** 5.5 mi from Rancho Nuevo towards Janos, ASU 20001–20014, Jul 1978 **24)** Rancho Nuevo, jct Cajon Bonito and Agua Blanca, Sierra San Luis, UTA 20299–309, Aug 1986 **25)** Cananea and vicinity, AMNH 53020–26, Jul 1946 **26)** Pools just below spring at Agua Dulce, Rancho Los Fresnos, 5.7 km NE of main ranch house, 37.3 km NNW Cananea, 31.31629°N, 110.35491°W, fre-ror-028, numerous visits 2006–2016 **27)** Lagunita, Rancho Los Fresnos, 33.4 km NW Cananea, 31.277335°N, 110.394782°W, numerous visits 2006–2016 **28)** Arroyo Los Alisos, Rancho Los Fresnos, 21.5 km (by air) ENE of Santa Cruz, 31.31638°N, 110.391°W, son-trv-16364, Jun 2009 **29)** Agua Dulce, Rancho Los Fresnos, 24.8 km (by air) ENE of Santa Cruz, 31.31737°N, 110.35534°W, son-trv-16391, numerous visits 2006–2016 **30)** Cattle pond, 17.2 km NE of Santa Cruz, 31.32732°N, 110.455°W, Apr 2015, May 2016 **31)** Cattle pond, 37.4 km NNW Cananea, 31.32238°N, 110.34708°W, Apr 2015 **32)** Road crossing of Arroyo Los Fresnos, 29.2 km NNW Cananea, 31.24377°N, 110.36202°W, Apr 2015 **33)** Road crossing of Arroyo Los Fresnos, 24.7 km NNW Cananea, 31.2103°N, 110.33341°W, Apr 2015 **34)** Cattle pond 37 km N Cananea, 31.32148°N, 110.31195°W, Apr 2015 **35)** Arroyo Los Fresnos, Rancho Los Fresnos, 18.7 km (by air) ENE of Santa Cruz, 31.28363°N, 110.40873°W, numerous visits 2006–2016 **36)** Cattle pond 32.1 km NNW Cananea, 31.27566°N, 110.34965°W, Apr 2015 **37)** Ciénega pools, Rancho Ciéneguita, 19.6 km NNW Cananea, 31.16527°N, 110.323259°W, May 2016 **38)** Cattle tank, 23.7 km N Cananea, 31.201008°N, 110.332242°W, Apr 2015 **39)** Ciénega pool, Rancho Los Fresnos, 37.5 km NNW Cananea, 31.304349°N, 110.431187°W, numerous visits 2006–2016 **40)** Ciénega on the Río Cocospera, Rancho El Aribabi, 0.26 km SE of Casa Grande, 19.3 km ENE Ímuris, 30.85529°N, 110.66315°W, ari-ror-036, numerous visits 2006–2016 **41)** Portrero del Alamo ciénega pools, Rancho Los Fresnos, 32.4 km NNW Cananea, 31.313948°N, 110.426943°W, numerous visits 2006–2016 **42)** Los Fresnos Cienega, cienega pools, 38.3 km NNW Cananea, 31.313878°N, 110.431554°W, numerous visits 2006–2016 **43)** Río Cocospera, 0.08 km ESE of Casa Grande (main ranch house) Rancho El Aribabi, 19.1 km ENE Ímuris, 30.85583°N, 110.66493°W, ari-ror-037, numerous visits 2006–2016 **44)** Rancho Los Pavos, Northern Jaguar Reserve, 48.1 km (by air) N Sahuaripa, 29.48944°N, 109.48944°W, pav-trv-083, Jun 2008 **45)** Ciénega de Saracachi, Rancho Agua Fría, 10.6 km (by air) ENE of Cucurpe, 30.35972°N, 110.59806°W, Oct 2010 **46)** Cattle tank, west side of road on the way into Rancho Los Pavos, Northern Jaguar Reserve, 46.4 km (by air) NNE of Sahuaripa, 29.47379°N, 109.185°W, 5009059c-11d9-457e-bd6a-c7070e23906d, Jun 2008 **47)** Cattle tank along the road between Rancho La Ventana and Babisal,

33.1 km (by air) NNE of Sahuaripa, Northern Jaguar Reserve, 29.33668°N, 109.12366°W, 8163d9b6-f70e-44c0-a1bc-3a13f411989b, Jun 2008 **48)** Remedios, Arroyo los Remedios, ca. 14 km (by air) E of Ímuris, 30.76222°N, 110.70139°W, son-trv-5161, Apr 2005 **49)** San Miguelito (ca. 5 km N of Bavispe), 30.517597°N, 108.969126°W, e271f186-f134-45d5-b503-3331a1902143, Jul 2008 **50)** SE of Rancho Los Alisos ranch house, 9.4 km (by air) WSW of Aconchi, Sierra Aconchi, 29.79846°N, 110.31816°W, Sep 2012 **51)** Cattle tank, Rancho El Aribabi, 25.6 km (by air) ENE of Ímuris, W slope of Sierra Azul, 30.828811°N, 110.58774°W, numerous visits 2006–2016 **52)** Arroyo Cuitaca, just south of MEX 2 bridge, 31.00664°N, 110.49477°W, Sep 2016 **53)** El Ranchito de Don Chano, Rancho Pueblo Viejo, 18.7 km (by air) E of Divisaderos, 29.6075°N, 109.27806°W, mde-10292, Nov 2016 **54)** Cattle pond, Northern Jaguar Reserve, 4.1 km NW Rancho La Ventana, 29.35601°N, 109.12277°W, Apr 2010 **55)** Rancho El Saucito, ca. 12 km (by air) SE of Bacadéhuachi, 29.76444°N, 109.05528°W, 5c770370-36f8-4c8f-ac83-14de1dfbd29, Jul 2008 **56)** Arroyo Guadalupe, 75 m S of international boundary, 43 km E Agua Prieta, 31.331958°N, 109.088749°W, May 2002 **57)** Arroyo El Púlpito, 33.3 km (by air) NNW of Bavispe, Sierra San Luis, 30.77731°N, 109.00467°W, son-trv-15729, Apr 2008 **58)** Arroyo Los Pilares at MEX 16, 24.7 km W of Maycoba, 28.39444°N, 108.79306°W, son-trv-5157, Nov 2000 **59)** Rancho La Mula, 28.2 km SE of Río Yaqui on MEX 16, 28.48778°N, 109.36639°W, son-trv-14616, Jan 2000 **60)** Rancho el Trigo, 14.8 km SE of Yécora, 28.30848°N, 108.79258°W, son-trv-15724, 15728, Oct 2008 **61)** Between Guisamopa and Cajon de Onapa, 28.72003°N, 109.106873°W, UCM 65687, Jan 2003 **62)** Represo La Leona, 1.5 km (by air) SE of Rancho el Bachán, 10.1 km (by air) NNW of Mazatán, Sierra Huérfana (= Mazatán), 29.08833°N, 110.17694°W, Apr 2014 **63)** Cañada El Flauta, Rancho El Flauta, Sierra de Mazatán, 29.1°N, 110.21389°W, son-trv-5153, Oct 2004 **64)** Represso Abajo, Rancho El Aribabi, 30.844977°N, 110.645319°W, Jul 2015, Jul 2016 **65)** Unnamed Arroyo, 15.6 km NE Santa Cruz, 31.31785°N, 110.46703°W, Apr 2015 **66)** Cattle pond, 12.2 km NE Santa Cruz, 31.31342°N, 110.50948°W, Apr 2015 **67)** Cattle pond 6.5 km NNE Santa Cruz, 31.28814°N, 110.57471°W, Apr 2015 **68)** Cattle pond 34.4 km N Cananea, 31.30759°N, 110.32256°W, Apr 2015 **69)** Reservoir, Rio San Rafael, 20 km NNE Cananea, 31.170181°N, 110.267571°W, Apr 2015 **70)** Arroyo Las Palomas, Sierra Azul, 30.819685°N, 110.54872°W, numerous visits 2006–2016 **71)** Cañon Evans, Sierra Los Ajos, 30.9717°N, 109.9621°W, Oct 2010 **72)** La Sal, 34.5 km (by air) E of Cananea, Sierra Los Ajos, 30.95709°N, 109.94772°W, Oct 2010 **73)** Unnamed Arroyo, 7.9 km W Yécora, 28.360072°N, 109.005806°W, Jul 2015 **74)** Rio Yécora, 4.9 km S Yecora, 28.327779°N, 108.926457°W, Jul 2015 **75)** Pond at Parque Tamosura on the eastern outskirts of Cananea, 30.999014°N, 110.255825°W, Sep and May 2016 **76)** Arroyo Quinc, NW slope of Sierra Elenita, 11 km WNW Cananea, 31.00974°N, 110.40274°W, Sep 2016 **77)** Cattle pond, just S Hwy 2, 6.2 km ENE Cananea, 31.015337°N, 110.230844°W, Sep 2016 **78)** Cajon Bonito at crossing of road to Agua Prieta, 31.12346°N, 109.29579°W, Apr 2008 **79)** Cattle tank, Rancho El Salto, Sierra La Purica, 17.3 km NNW Nacozari, 30.529073°N, 109.726738°W, Sep 2013 **80)** Unnamed arroyo, Sierra La Purica, 16.1 km NNW Nacozari, 30.520662°N, 109.723801°W, Sep 2013 **81)** Cattle tank, Sierra La Purica, 14.6 km NNW Nacozari, 30.511344°N, 109.711724°W, Sep 2013 **82)** Cattle tank, Sierra La Purica, 14.7 km NNW Nacozari, 30.51253°N, 109.709955°W, Sep 2013 **83)** Cattle tank, 35.5 km N Cananea, 31.30759°N, 110.32256°W, Apr 2015 **84)** Cattle tank 3.6 km NW Cananea, 31.004174°N, 110.322774°W, May 2016 **85)** Cattle tank 4.9 km NW Cananea, 31.007806°N, 110.335817°W, May 2016 **86)** Spring box, Sierra Elenita, 10.1 km WNW Cananea, 31.001095°N, 110.393177°W, Aug 2016 **87)** Cattle tank 6.5 km NE Santa Cruz, 31.286892°N, 110.569997°W, May 2016 **88)** Cattle tank 24.1 km NE Cananea, 31.066555°N, 110.053986°W, May 2016 **89)** Cattle tank 11.2 km NE Cananea, 31.069551°N, 110.217144°W, May 2016 **90)** Corral pond fed by windmill, 12.1 km NE Santa Cruz, 31.323912°N, 110.529366°W, May 2016 **91)** Laguna Patos, 12 km NE Cananea, 31.055709°N, 110.182061°W, May 2016 **92)** Cattle tank, 13.9 km NNE Cananea, 31.112049°N, 110.252072°W, May 2016 **93)** Cattle tank 13.3 km N Cananea, 31.109817°N, 110.305643°W, May 2016 **94)** Cattle tank, 11.7 km NE Santa Cruz, 31.306442°N, 110.509822°W, Apr 2015 **95)** Cattle tank 5.2 km NE Santa Cruz, 31.269054°N, 110.56261°W, May 2016 **96)** Cattle tank, 35.4 km NNW Cananea, 31.302326°N, 110.358232°W, May 2016 **97)** Cattle tank, 34.4 km N Cananea, 31.298691°N, 110.322978°W, Apr 2015 **98)** Cattle tank, 41.1 km NW Cananea, 31.30297°N, 110.521795°W, Apr 2015 **99)** Cattle tank, 29.7 km NNW Cananea, 31.24974°N, 110.3655°W, Apr 2015 **100)** Cattle tank 33 km NNW Cananea, 31.284139°N, 110.338573°W, May 2016 **101)** El Barrilito and acequia ditch just downstream of Hwy 2, Cananea, 30.997793°N, 110.28716°W, Sep 2016.