Species Status Assessment Report

for the

Roundtail Chub (*Gila robusta*) in the Lower Colorado River Basin

Photo by Randy Babb

Version 2.1, March 2022

U.S. Fish and Wildlife Service

Arizona Ecological Services Field Office

Phoenix, AZ

Version History:

Version 2.1 is a report of the Species Status Assessment (SSA) for roundtail chub (*Gila robusta*) in the Lower Colorado River and incorporates feedback from peer and partner review.

Version 2.0 was a draft report of the SSA for roundtail chub in the Lower Colorado River. This version was intended exclusively to facilitate peer and partner review of the draft document and should not be referenced or cited as an agency document. We have significantly updated and rewritten this version since the previous Version 1 of a related SSA report.

Biologists from the U.S. Fish and Wildlife Service, including Ryan Gordon, Shaula Hedwall, Nathan Franssen, Justin Shoemaker, Justin Bohling, Nathan Allan, Mike Dick, and Steven Mussmann, prepared this report. We received significant assistance in data acquisition and assessment as well as drafting of the report from other members of the Roundtail Chub Species Status Assessment Technical Team: Tony Robinson (retired), Brian Hickerson, and Zach Beard of Arizona Game and Fish Department (AGFD), Matthew Zeigler and Jill Wick of New Mexico Department of Game and Fish (NMDGF), and Conor McGowan and Daniel Fitzgerald of the U.S. Geological Survey (USGS).

Previous Version:

Version 1.0 was the Species Status Assessment Report for the Headwater Chub and Lower Colorado River Distinct Population Segment of Roundtail Chub, which we completed in September 2015. This report was prepared to inform a previous 12-month petition finding for roundtail chub in the lower Colorado River and the headwater chub (80 FR 60753).

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1 INTRODUCTION

The roundtail chub (*Gila robusta*) is a species of freshwater fish found in the Colorado River basin across five different states (Arizona, Colorado, New Mexico, Utah, Wyoming). Due to hydrological, geographical, ecological, and genetic factors, the species has traditionally been divided into an Upper Colorado River basin and a Lower Colorado River basin section, demarcated by the Glen Canyon Dam (Figure 1-1) (Voeltz 2002, p. 2). The Lower Colorado River basin includes populations found in waterways downstream of the dam, which includes the Bill Williams, Gila, and Little Colorado River drainages in Arizona and New Mexico. In response to a petition (70 FR 39981) to list the Lower Colorado River portion of the roundtail chub as a Distinct Population Segment (DPS) under the Endangered Species Act of 1973, as amended (Act), we have prepared this Species Status Assessment (SSA) Report. This SSA Report documents the results of the comprehensive status review for the roundtail chub in the Lower Colorado River basin to inform the listing decision and future conservation efforts.

The SSA framework (Smith *et al.* 2018, entire) summarizes information compiled and reviewed by the U.S. Fish and Wildlife Service (Service) to conduct an in-depth review of a species' biology, evaluate its biological status and influencing factors, and assesses the resources and conditions needed to maintain long-term viability. Using the SSA framework (Figure 1-2), we consider what a species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (together, the 3R's) (Smith *et al.* 2018, entire). To sustain populations over time, a species must have the capacity to withstand: (1) environmental and demographic stochasticity and disturbances (Resiliency), (2) catastrophes (Redundancy), and (3) novel changes in its biological and physical environment (Representation). A species with a high degree of the 3R's is better able to adapt to novel changes and to tolerate environmental stochasticity and catastrophes. In general, species viability will increase with increases in resiliency, redundancy, and representation (Smith *et al.* 2018, p. 306).

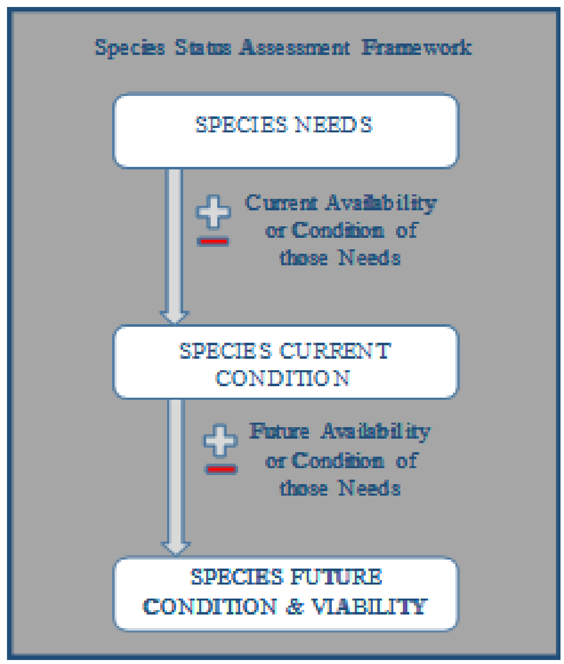

Figure 1-2: Species Status Assessment Framework.

Figure 1-1: Map of the Upper and Lower Colorado River basins, along with the three subbasins in the Lower Colorado River basin that are part of the roundtail chub range. Glen Canyon and Hoover Dams are highlighted due to being impassible fish barriers.

The definitions of the 3R's are described below. For the purpose of this assessment and considering the 3Rs, we are treating the Roundtail Lower Colorado River basin as the entity by which we compare the status of the species.

Resiliency is the ability of a species to withstand environmental stochasticity (normal, year-to year variations in environmental conditions such as temperature, rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford *et al.* 2011, p. 40). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions. We can best gauge resiliency by evaluating population level characteristics such as: demography (abundance and the components of population growth rate -- survival, reproduction, and emigration), genetic health (effective population size and heterozygosity), connectivity (gene flow and population rescue), and habitat quantity, quality, configuration, and heterogeneity.

Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments-- referred to as adaptive capacity--is essential for viability, as species need to continually adapt to their continuously changing environments. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. Theoretically, the more representation, or diversity, the species has, the higher its potential of adapting to changes (natural or human caused) in its environment.

Redundancy is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population heath and for which adaptation is unlikely. Redundancy is about spreading the risk and can be measured through the duplication and broad distribution of resilient populations across the range of the species. The more resilient populations the species has, distributed over a larger area, the better chances that the species can withstand catastrophic events.

To evaluate the biological status of the Lower Colorado River roundtail chub, both currently and into the future, we assessed a range of conditions that allowed us to consider the species' resiliency, representation, and redundancy. This SSA provides a thorough assessment of biology and natural history, and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species. It provides a compilation of the best available scientific and commercial information, and a description of past, present, and likely future risk factors to roundtail chub in the Lower Colorado River basin. Our intent is to update the SSA as new information becomes available and to support all functions of the Endangered Species Program from Listing to Consultations to Recovery.

2 LOWER COLORADO RIVER BASIN ROUNDTAIL CHUB BACKGROUND

2.1 Taxonomy

The taxonomic description of the *Gila robusta* complex in the Lower Colorado River basin has a complex and confusing history. There are fifteen specific names and seven generic names taxonomists have applied to fishes in the *G. robusta* complex within the Lower Colorado River basin (Copus *et al.* 2018, p. 5). Fish now considered to be roundtail chub in the Lower Colorado River basin have been classified in the past as a single species, assigned as different species (*G. robusta*, *G. nigra*, and *G. intermedia*), subspecies of *Gila robusta,* or as part of a ‘‘*Gila robusta* complex’’(Miller 1945; Holden 1968; Rinne 1969; Holden and Stalnaker 1970; Rinne 1976; Smith *et al.* 1979; DeMarais 1986; Rosenfeld and Wilkinson 1989; Dowling and DeMarais 1993; Douglas *et al.* 1998; Minckley and DeMarais 2000; Gerber *et al.* 2001). As noted by nearly all researchers investigating the systematics of *Gila* spp., the taxonomic situation is complicated and problematic (Holden and Stalnaker 1970, pp. 418-419; Minckley 1973, pp. 102-103; Minckley and DeMarais 2000, p. 251; Gerber et al. 2001, p. 2028; Schönhuth *et al*. 2014, p. 210 ; Copus *et al.* 2018, p. 2; Chafin *et al.* 2021, p. 2-3) and ongoing genetic and morphologic analyses of chubs in the Gila River basin continue to yield conflicting results (Copus *et al.* 2018, entire; Chafin *et al.* 2021, entire).

Fishes in the Lower Colorado River basin *G. robusta* complex were first identified by Baird and Girard (1853a, p. 369) as *Gila robusta*, by Baird and Girard (1853b, p. 389) as *G. grahamii*, by Girard (1856, p. 41) as *Gila intermedia*, and by Cope and Yarrow (1875, p. 663) as *G. nigra*. After much initial debate the consensus was to treat all four previously identified species as synonymous with *G. robusta* until Rinne (1969, p. 43). Rinne (1969, entire) recognized two distinct species *G. robusta* and *G. intermedia* and he considered *G. nigra* as synonymous with *G. intermedia* and *G. grahamii* as a subspecies of *G. robusta* (*G. robusta grahamii*). Later, Minckley and DeMarais (2000, p. 254) recognized three separate species, *G. robusta*, *G. intermedia*, and *G. nigra*, with the *G. robusta grahamii* recognized by Rinne (1969) considered synonymous with *G. robusta*. Minckley and Demarais (2000, p. 253) based their conclusions upon differences in mean morphological characteristics between populations rather than by diagnosable morphological or molecular characters of individuals. They developed a taxonomic key for use in the identification of what they recognized as three distinct species (Minckley and DeMarais 2000, pp. 254-255). Subsequent research found that using this taxonomic key did not reliably identify individuals to the species assumed to be occupying a particular area (Brandenburg *et al.* 2015, p. 18; Moran *et al.* 2017 pp. 6; Carter *et al.* 2018, entire). In addition, studies failed to find morphological or genetic characteristic that could successfully distinguish the three putative species as defined by Minckley and DeMarais (2000) (Gerber *et al.* 2001, p. 2037; Schwemm 2006, p. 31; Schönhuth *et al*. 2014, pp. 211, 223; Dowling *et al.* 2015, p. 17; Carter *et al.* 2018, p. 287; Copus *et al.* 2018, p. 19).

Since experts could not reliably distinguish the three putative species (Carter *et al*. 2018, pp. 287-288), in 2015 the Arizona Game and Fish Department (AGFD) asked the American Fisheries Society and American Society of Ichthyology and Herpetology Joint Committee on the Names of Fishes (AFS/ASIH) to review the taxonomic status of the *G. robusta* complex in the Lower Colorado River basin. In 2017, the AFS/ASIH published a joint report on the taxonomy of *Gila* in the Lower Colorado River basin (Page *et al*. 2017, entire). They concluded that the available evidence did not support species-level status for *G. nigra* and *G. intermedia* and they collapsed the three into *G. robusta*, recognizing only a single species (Page *et al.* 2017, p. 459).

Most recently, Chafin *et al.* 2021 (entire) suggested resurrecting the three species (*G. robusta*, *G. intermedia*, and *G. nigra*) as distinct entities based upon the results of extensive geographic and genomic sampling. They concluded that incomplete and/or biased sampling as well as the complex evolution and biogeography of the Colorado River may explain why other research did not obtain similar results (Chafin *et al.* 2021, pp. 8-10). Additionally, results of Chafin *et al.* 2021 (pp. 7-11) supported considering Upper Colorado River basin *G. robusta* as a distinct species from Lower Colorado River basin *G. robusta*.

Although there is continued deliberation regarding these evolutionary relationships, for this SSA we followed the conclusions of the AFS/ASIH report and considered there to be only one species, *G. robusta*, in the Lower Colorado River basin. This means that this SSA considers populations that we previously considered headwater chub (*G. nigra*) or Gila chub (*G. intermedia*) as roundtail chub within the Lower Colorado River basin.

2.2 Species Description

The roundtail chub is a member of the family Cyprinidae, a speciose family of freshwater fishes that includes species commonly referred to as carps and minnows. The body coloration of roundtail chub varies from silver, olive, dark gray, brown, or black with diffuse longitudinal stripes and a lighter belly speckled with gray. When in spawning condition, roundtail chub may develop a red-orange coloration on the lower half of the cheek and along the fin bases. Roundtail chub have a deeply compressed body, flat head, slender caudal peduncle, and an angle along the anal fin base that continues into the caudal fin. Depending on the size of the natal stream, adult roundtail chub vary in size from 100 to 350 millimeters (mm) (4 to 14 inches (in)) but can reach 500 mm (20 in) (Minckley 1973, pp. 100–103; Sublette *et al.* 1990, pp. 126–129; Propst 1999, pp. 18-19, 23-25; Voeltz 2002, pp. 8-11; Bestgen 1985a, entire).

2.3 Life History

Depending on the stream size, roundtail chub can live between five and ten years with some individuals living for more than ten years in larger streams systems (Bestgen 1985a, p. 65; Neve 1976, pp. 13, 15; Bezzerides and Bestgen 2002, p. 21; Brouder 2005, p. 867). Maturity occurs between two and five years of age; however, total length at maturity varies by location (Bezzerides and Bestgen 2002, p. 21; Brouder *et al*. 2000, p. 12; Griffith and Tiersch 1989, p. 133; Schultz and Bonar 2006, p.63; Bestgen 1985a, pp. 68-74). Spawning typically occurs between April and May (Bestgen 1985a, pp. 56-57; Brouder *et al.* 2000, p. 12; Minckley 1981, p. 189; Brouder *et al*. 2006, pp. 261–262; Bestgen 1985b, p. 7; Bryan *et al.* 2000, pp. 27–28; Bryan and Robinson 2000, pp. 20–21), but in some habitats it can occur as early as February or March (Neve 1976, pp. 13-14; Schultz and Bonar 2006, pp. 40). Spawning involves one female flanked by two or three males with their vents near each other (Brouder *et al.* 2006, p. 261). The female rapidly "quivers" her caudal region while the males follow suit, pressing their bodies against the female. Roundtail chub release gametes over the stream substrate (Bonar *et al.* 2011, p. 11; Neve

1976, pp. 13-14; Brouder 2001, p. 261). Egg production ranges from 600 to 33,440 (Neve 1976, p. 13; Bestgen 1985a, p. 66; Brouder *et al.* 2000, p. 261). Eggs are adhesive (Neve 1976, p. 14; Brouder *et al*. 2000, p. 261) to spawning substrates (*e.g.*, rocks) and hatch within five to six days (Bonar *et al.* 2011, p. 22). There is no parental protection of young (Stefferud *et al.* 2011, p. 5).

Roundtail chubs are omnivores, consuming aquatic and terrestrial invertebrates, aquatic plants, detritus, and fish and other vertebrates in proportional to their availability. Larvae feed on diatoms and filamentous algae (Neve 1976, p. 10) with juveniles eating chironomid larvae and ephemeroptera nymphs (Vanicek and Kramer 1969, p. 202) along with algae, trichopterans, and ostracods (Bestgen 1985a, p. 48). Larger juveniles and adults consume aquatic and terrestrial insects, crustaceans, fish, plant matter, and occasionally small lizards (Bezzerides and Bestgen 2002, p. 23; Griffith and Tiersch 1989, pp. 133-134; Rinne and Minckley 1991, p. 22).

2.4 Individual Resource Needs

Roundtail chub are found in cool to warm waters of rivers, streams, and cienegas, and often occupy the deepest pools and eddies present in the stream (Minckley 1973, p. 101; Brouder *et al*. 2000, pp. 6–8; Minckley and DeMarais 2000, p. 255; Bezzerides and Bestgen 2002, pp. 17–19; Rinne 1976, p. 82; Weedman *et al.* 1996, pp. 11-12; Shultz and Bonar 2006, entire). Adult roundtail chub favor slow-moving, deep pools with access to feeding areas and cover such as large rocks or boulders, root wads, undercut banks, overhead bank cover, and woody debris (Bestgen and Propst 1989, pp. 402-410; Bezzerides and Bestgen 2002, pp. 18; Brouder *et al*. 2000, pp. 6–7; Bryan and Hyatt 2004, pp. 9; Schultz and Bonar 2006, pp. 21-25.; Rinne and Minckley 1991, pp. 22-23; Nelson 1993, p. 5; Weedman *et al.* 1996, pp 11-12). Spawning occurs in pool, run, and riffle habitats with slow to moderate water velocities (Propst 1999, p. 24; Brouder *et al.* 2000, p. 12; Voeltz 2002, p. 16; Schultz and Bonar 2006, entire). Roundtail chub larvae use low velocity habitats (Ruppert *et al.* 1993, p. 397; Schultz and Bonar 2006, entire). Young of the year roundtail chub occupy shallow (less than 50 cm (19.7 in) in depth) and low velocity waters with vegetated shorelines (Brouder *et al.* 2000, pp. 6–8; Lanigan and Berry 1981, p. 392; Schultz and Bonar 2006, p. 24). Water temperatures of habitats occupied by roundtail chub vary seasonally between 0 and 32˚C (32 to 90˚F) (Bezzerides and Bestgen 2002, p. 19; Bonar *et al*. 2010, p. 3). Lethal water temperature limits are around 34˚C (93˚F) (Carveth *et al.* 2006, pp. 1435–1436). Spawning is associated with water temperatures of 14 to 24˚C (57 to 75˚F) with most at 18 to 20˚C (64 to 68˚F) (Bezzerides and Bestgen 2002, p. 21; Brouder *et al.* 2006, pp. 261–262). We provide further details of the individual needs of roundtail chub during the various life stages in Appendix A.

3 LOWER COLORADO RIVER BASIN ROUNDTAIL CHUB VIABILITY

3.1 Population resiliency

Resiliency is having sufficiently large populations for the roundtail chub within the Lower Colorado River basin to withstand stochastic events. The quantity and quality of physical habitat available, the spatial distribution of habitat, and environmental variables that facilitate reproduction govern the resiliency of roundtail chub populations.

3.1.1 Habitat Availability

Resilient fish populations need sufficient habitat to provide the range of conditions needed to complete their life cycle (*i.e.*, spawning, nursery, adult, and refugial habitat) (Harig and Fausch 2002, p. 546; Young *et al.* 2005, p. 2406). Based on the life history information presented in Chapter 2, roundtail chub have preferences for certain physical features (*i.e*., pools and shorelines with low velocities). The literature emphasizes the benefits of habitat complexity through the presence of multiple pools with varying types of instream cover (boulders, pools, and woody vegetation) for adults and other types of cover along the shorelines used by young-of-year and juveniles. The abundance and quality of those resources is a gauge of how well that stream can support a resilient population. To fully evaluate the quality of a stream for roundtail chub, measurements of the preferred habitats relative to the physical conditions present in the stream are optimal. However, this type of information is available for very few streams that harbor roundtail chub, and it may not fully encompass the needs of all life stages.

3.1.2 Spring flooding

Many fishes, including roundtail chub, time their reproductive cycle to the seasonal, highly variable flow regimes of streams (Taylor and Miller 1989, p. 36; Brouder 2001, p. 307; Stefferud *et al.* 2011, p. 8). Floods are a part of the natural hydrograph and are an important abiotic factor affecting fish (Resh *et al.* 1988; Meffe and Minckley 1987; Poff and Allen 1995; Rinne and Stefferud 1996; Taylor *et al.* 1996; Poff *et al.* 1997). Maintenance of natural flow regime is important to roundtail chub population resiliency because recruitment of chub to age one is dependent upon late winter/early spring floods (Brouder 2001, p. 306-307). High flows facilitate ecological productivity and diversity, and the natural timing of high or low stream flows may initiate life cycle activities (*e.g.*, spawning, egg hatching, rearing). Roundtail chub were the only species sensitive to reduced streamflow in Fossil Creek (Marks *et al*. 2009, p. 5).

3.1.3 Connectivity

Habitat connectivity is likely important to roundtail chub population resiliency because they occur within linear river systems where intermittent or permanent connections (spatial continuity within the river network) supports migration and gene flow within and between populations (Meffe and Vrjenhoek 1988, p. 8; Jaeger *et al.* 2014, p. 13894). Maintenance of natural flow regimes, including flooding, support the recruitment and movement of young-of-year chub (Brouder 2001, p. 301). In addition, fish need diverse habitats to move into for different life history needs. In the lower Salt and Verde rivers, the majority of PIT-tagged roundtail chub were found to be somewhat sedentary with larger movements observed after a significant short-term spike in discharge (Bryan and Robinson 2000, p. 30).

Connectivity is also important to support gene flow, especially for populations that may occupy smaller streams that support lower abundances. Exchange of genes between these smaller groups can elevate the overall effective size of a population. The literature on fish in general does emphasize that larger total population sizes that support at least the minimum effective population size are needed to provide greater certainty of persistence over time. Therefore, resilient populations have a sufficient effective population size to avoid adverse genetic consequences on the population (Frankham *et al.* 2014, entire).

3.2 Lower Colorado River Basin Redundancy and Representation

Redundancy is having enough populations of roundtail chub within the Lower Colorado River basin to withstand catastrophic events. The wider the distribution of resilient populations and the larger the number of populations, the more redundancy the species will have. This redundancy reduces the risk that a single catastrophic event at any one time could negatively affect a large portion of the range within the Lower Colorado River basin. Species that are well-distributed across their historical range (*i.e*., having high redundancy) are less susceptible to extinction and more likely to be viable than species confined to a small portion of their range (Carroll *et al*. 2012, entire; Redford *et al*. 2011, entire).

In the case of roundtail chub, catastrophic events such as large, high intensity wildfire and stream dewatering can cause localized affects to populations by making streams temporarily inhospitable. The presence of multiple resilient populations distributed across a broad portion of the species' historical range would enhance roundtail chub viability. This would minimize the potential for a single catastrophic event to eliminate a large portion of extant populations.

Representation considers the breadth of diversity within roundtail chub within the Lower Colorado River basin that may facilitate adaptation to changing environmental conditions. Relevant diversity can extend to genetic, ecological, or phenotypic variation within and among populations. For Lower Colorado River basin roundtail chub, we considered two forms of diversity in assessing representation. First, genetic studies of roundtail chub have shown that there is substantial genetic structure between individual populations, with gene flow higher among roundtail chub inhabiting mainstem reaches than isolated, headwater populations (Dowling *et al.* 2015, pp. 15–16). Genetic variation has also been shown to be partitioned among watersheds, especially between the Bill Williams and Gila Rivers, as well as between sub-watersheds within the Gila River (Dowling *et al.* 2015, pp. 12–16; Copus *et al*. 2018, pp. 15–16). We do acknowledge that some populations observed as being genetically distinct were previously recognized as headwater or Gila chub (Dowling *et al.* 2015, entire; Marsh *et al*. 2017, entire; Copus *et al*. 2018, p. 20). However, multiple studies have failed to find consistent genetic groupings among populations previously recognized as these species (Dowling *et al*. 2015, pp. 13–16; Copus *et al*. 2018, entire). Therefore, we did not use the previous taxonomic classifications to base our measures of representation.

Ecologically, Lower Colorado River basin roundtail chub have a wide distribution across notable environmental gradients. Across the range there are differences in climatic variables such as temperature and average snowfall. Given the historical range (see Chapter 5), roundtail chub would have occupied a diverse array of habitats ranging from montane headwater streams to large, mainstem rivers flowing through desert environments. Some populations persist in highly intermittent streams that experience regular contraction during droughts. Roundtail chub occur in the highlands of the Mogollon Plateau, Gila Mountains, and several so-called Sky Island ranges in southern Arizona. All of these have distinct geological histories and environmental conditions, which have likely influenced roundtail chub as well (Dowling *et al.* 2015, pp. 15–16).

Quantifying genetic and ecological diversity is challenging given the unique site-specific conditions that roundtail chubs may experience. For this SSA, we defined units for representation based on relevant watershed boundaries within the species range. We used the U.S. Geological Survey's (USGS) Hydrological Unit Codes (HUC) to identify potential boundaries and selected the 6-digit unit codes (HUC6) as our representation units. These watersheds provide the resolution we desired to characterize relevant variation across the species range and correspond to broad environmental and geologic divisions as well. In addition, natural resource management agencies use these units to collect data on roundtail chub and correspond to patterns of genetic variation (Dowling *et al*. 2015, entire; Copus *et al*. 2018, entire).

4 FACTORS AFFECTING LOWER COLORADO RIVER BASIN ROUNDTAIL CHUB VIABILITY

4.1 Overview

The following discussion provides a summary of the factors that are affecting or could be affecting the current and future condition of the roundtail chub throughout the Lower Colorado River basin.

4.2 Nonnative Species

The establishment of nonnative fishes is one of the most significant risk factors and impediments to conservation of native fish in the Lower Colorado River basin due to competition for habitat (space and resources) and predation effects (Minckley and Deacon 1991; Carlson and Muth 1989, p. 220; Clarkson *et al.* 2005, p. 20; Mueller 2005, pp. 10–12; Olden and Poff 2005, p. 75; Minckley and Marsh 2009, p. 51). Competition from nonnative fish species reduces the space and resources available to all fish (habitat), and predation affects recruitment of young-of-year native fish, particularly in small populations (Marks *et al.* 2009, p. 5). Declines in native fish, including roundtail chub, are largely attributable to predation, with early life stages being the most vulnerable (Minckley 1983, p. 182; Marks *et al.* 2009, p. 5). For example, lower West Clear Creek showed a reduction in roundtail chub after smallmouth bass (*Micropterus dolomieu*) became a significant part of the fish community (Brouder *et al.* 2000, pp. 9, 13). Presence of flathead catfish (*Pylodictis olivaris*) resulted in a sharp decline of roundtail chub in the upper Salt River (AGFD 1996, p. 1) and the San Francisco and Gila Rivers (Bestgen and Propst 1989, p. 410). Green sunfish (*Lepomis cyanellus*) and smallmouth bass invaded Fossil Creek from the Verde River, and until managers removed these nonnative fishes, they competed with and preyed upon roundtail chub (Marks *et al.* 2009, pp. 5-8). Therefore, nonnative fish have and continue to pose a substantial population level threat to native fish in the southwestern U.S. (Clarkson *et al.* 2005, pp. 9-10; Marks *et al.* 2009, p. 9).

Table 4-1 identifies nonnative species that affect roundtail chub and describes their effect. Of these species, green sunfish, smallmouth bass (*Micropterus dolomieu*), flathead catfish (Fuller 1999, p. 208), and channel catfish (*Ictalurus punctatus*) are among the fastest expanding nonnative fishes in the basin and are considered to have the most negative effects to native fish communities (Olden and Poff 2005, pp. 83-84). We define age classes in Appendix A.

Table 4-1: List of nonnative species and their potential effects on roundtail chubs.

Nonnative Species	Age Classes of Chub Preyed Upon	Age Classes that Prey on Chub	Habitat Overlap with Chub	Competition Effects to Chub	Level of Effect to Chub
Green sunfish	Larvae to juveniles	Juveniles to adults	Yes: uses multiple habitat types	Consumes invertebrates.	High
Flathead catfish	Juveniles and adults	Sub-adult, adult	Yes: uses slow and deep areas	Consumes invertebrates.	High
Smallmouth bass*	Larvae to adults	Sub-adult to adult	Yes	May exclude chub from preferred pools. Consumes invertebrates.	High
Rock bass (*Ambloplites rupestris*)	Larvae to juveniles	Sub-adult to adult	Yes: pools	Uses pool habitat. Consumes invertebrates.	Medium
Channel catfish	Juveniles to sub-adults	Adults	Yes: deep water areas	Uses deep pools, slow-moving waters. Consumes invertebrates.	Medium
Black bullhead (*Ameiurus melas*)	Larvae to juveniles	Adults	Yes	Displace from pool habitat. Consumes invertebrates.	Medium
Yellow bullhead (*Ameiurus natalis*)	Larvae to juveniles	Sub-adult to adult	Yes	Uses pool habitat. Defends nest and young. Consumes invertebrates.	Medium
Red shiner	Larvae	Adult	Yes: shallow habitats	Consumes invertebrates.	Medium
Brown trout (wild) (*Salmo trutta*)	Larvae to sub-adult	Sub-adult to adult	Yes: pools	Consumes invertebrates.	Medium
Largemouth bass	Larvae to - adults	Sub-adult to adult	Yes: low velocity areas	Consumes invertebrates.	Low (lack of overlap in occurrence)
Common carp (*Cyprinus carpio*)	Eggs primarily	Sub-adult to adult	Yes: uses most habitat types	Consumes invertebrates.	Low

Nonnative Species	Age Classes of Chub Preyed Upon	Age Classes that Prey on Chub	Habitat Overlap with Chub	Competition Effects to Chub	Level of Effect to Chub
Fathead minnow (*Pimephales promelas*)	Larvae	Adults	Yes: uses slow water habitats	Consumes invertebrates.	Low
Rainbow trout (wild) (*Oncorhynchus mykiss*)	Larvae to juveniles	Adults	Yes: pools	Uses pool habitat.	Low
Mosquitofish	Larvae	Adults	Yes: shallow vegetated areas	Displaces from pool habitat.	Low
Crayfish	Larvae, small to sub-adult	Adults	Yes: uses all habitat types	Will injure/kill fish, alters habitat by burrowing into stream banks and removing aquatic vegetation., may compete with chub for food resources reduce the growth rates of native fish through competition for food, prey on fish eggs and larvae.	Low
Bullfrog (*Rana catesbeiana*)	Larvae to juveniles	Adults	Yes: uses shallow margin areas	Consumes fish, invertebrates, found mostly in shallow waters where young-of-the-year or juveniles may be present.	Low

*In some areas, genetic information indicates that fish previously thought to be smallmouth bass, are actually redeye bass (*Micropterus cooosae*), see Valente *et al.* 2021.

The effect of different nonnative fish species is not equal, and roundtail chub can persist in streams despite the presence of one or more nonnative species (Propst *et al.* 2008, p. 1249). We do not understand the mechanisms that allow for co-existence in any particular stream, but roundtail chub populations seem to be more persistent in the presence of nonnatives (Minckley 1973, p. 101). The amount and quality of habitat available, the flow regime, the nonnative species present (*e.g.*, flathead catfish, a high-level predator, versus fathead minnow), and the abundance of nonnative species are important factors to consider (Propst *et al.* 2008, p. 1251). In addition, effects to habitat, such as long-term drought (Jaeger *et al.* 2014, pp. 13894-13895), flow depletion or other habitat modification, may also increase the effect of nonnatives on roundtail chub. We acknowledge that while roundtail chub do co-exist with nonnatives in several streams this does not mean that nonnatives are not affecting them or they are not having population level effects, as demonstrated by the research showing the importance of the removal of nonnative fish in Fossil Creek to roundtail chub persistence (Marks *et al.* 2009, entire). Native fish, including roundtail chub, increased by almost 70-fold when managers removed green sunfish and smallmouth bass from Fossil Creek (Marks *et al.* 2009, p. 7). In most streams, if "high effect" (Table 4-1, *i.e*., green sunfish, flathead catfish, and smallmouth bass) or "medium effect" species (Table 4-1, *i.e*., rock bass, channel catfish, black bullhead, yellow bullhead, red shiner, and brown trout) are present, they will negatively affect the resiliency of roundtail chub populations (*e.g.*, Bestgen and Propst 1989, p. 410; Brouder *et al.* 2000, pp. 9, 13; Marks *et al.* 2009, p. 8).

4.3 Streamflow

Streamflow quantity and timing are essential components of water supply, water quality, and the ecological integrity of river systems and may, at least temporarily, cause declines in some nonnative fish species (Poff *et al.* 1997, p. 769, Brouder 2001, p. 307; Stefferud *et al.* 2011, p. 12). The streamflow defines where different habitats (*e.g*., pool, riffle) occur within a stream as well as channel geomorphology and water temperature (Poff *et al.* 1997, p. 769). Roundtail chub are sensitive to reduced streamflow (Marks *et al.* 2009, p. 5) and maintenance of the natural flow regime, including seasonal high flow events, is important for reproduction, recruitment, and connectivity within and between roundtail chub populations (Brouder 2001, pp. 306-307, Stefferud *et al.* 2011, p. 12). Therefore, we also consider reductions in streamflow quantity and timing to be a significant risk factor to roundtail chub in the Lower Colorado River basin.

Reduction and/or alteration in streamflow can result in a loss of hydrologic connectivity and increased fragmentation within and among streams (Ruhi *et al.* 2016, pp. 469-480; Jaeger *et al.* 2014, pp. 13894-13895). Reductions in hydrologic connectivity can prevent spawning-related movement and limit access to breeding, rearing, foraging, hiding areas, and can result in stranding of fish (Jaeger *et al.* 2014, p. 13897). In addition, during drought, stream intermittency or isolation may cause deterioration of water quality resulting in increases in physicochemical extremes of temperature, dissolved oxygen, pH, and nutrient loading (Lake 2000, p. 578; Lake 2003, p. 1165). Streams supporting a diversity of refugia (*i.e*., pools or other mesohabitats that remain wetted) during drying periods can increase the chances of individuals, populations, and communities surviving until habitats are rewetted and connected (Magoulick and Kobza 2003, pp. 1187-1188; Davey and Kelly 2007, p. 1719; Stefferud *et al.* 2011, p. 11). Hydrological connectivity within streams allows for larger contiguous habitat areas and the recolonization of portions of streams adversely affected by stochastic events (Jaeger *et al.* 2014, p. 13894). As natural and human-caused changes reduce the amount of water in streams, streams may continue to dry and contract longitudinally and laterally, decreasing the amount of habitat available to roundtail chub (Jaeger *et al.* 2014, p 13898). This reduction can result in division of two previously connected streams or create isolated refuges within streams (Propst *et al.* 2008, p.

1250), both of which contribute to fragmentation and isolation of populations (Jaeger et al 2014, pp. 13896, 13989).

Loss of natural habitat connectivity and increased fragmentation can also result in genetic isolation within populations of roundtail chubs potentially leading to inbreeding depression and loss of evolutionary potential thereby increasing the extirpation risk in small, isolated populations (Schwemm 2006, p. 28). Isolated and small populations represent a potential genetic bottleneck that could adversely affect populations through inbreeding depression and genetic drift making them more vulnerable to stochastic events that might further reduce their population sizes.

Humans have altered streams through surface water diversions (including dams) and alluvial groundwater pumping. The creation of large reservoirs in the 20th century, such as those on the Salt and Verde rivers, eliminated natural streamflow, modified flow seasonality and variability and generally increased minimum flows while decreasing maximum flows (Poff *et al.* 2007, p. 5732-5733; Mims and Olden 2013, p. 51). The modified streamflow because of the dams likely favors nonnative species and disadvantage native species, including roundtail chub. These dams, as well as low-head diversion dams, also prevent movement upstream and downstream, resulting in fragments of occupied stream where there was historically full connectivity. The dams also modify habitat both above and below the dams, making it less hospitable to native fishes (Mims and Olden 2013, pp. 58-59). Because the Verde and Salt rivers are significant streams in the Lower Colorado River basin and historically provided for connectivity of chub populations, the legacy effect of these dams is still affecting chub dispersal and connectivity in the Verde and Salt river systems today.

In the Lower Colorado River basin, development of ground-water resources since the late 1800s has resulted in the elimination or alteration of many perennial stream reaches, wetlands, and associated riparian ecosystems (Wirt 2005, p. A17; Leake and Pool 2010, pp. 4-5; Barlow and Leake 2012, entire; Konikow 2013, pp. 25-26). Because of the effects of groundwater pumping, portions of the Salt, Gila, Santa Cruz, San Pedro, and Verde rivers that once flowed year-round now have sections that are dry and flow only following storms or snowmelt (Wirt 2005, p. A17; Leake and Pool 2010, p. 11; Verde River Basin Partnership 2015, p. 11). Local groundwater provides nearly all the water used for municipal, domestic, and industrial consumption in the upper and middle Verde River watersheds, plus a substantial part of the water used for agricultural irrigation. In the upper Verde River, groundwater pumping reduced the perennially free-flowing length of the Verde River by about 5.7 miles (9.2 kilometers[km]) from its predevelopment source at Del Rio Springs to the river’s current source springs about 0.1 mile (0.16 km) below the mouth of Granite Creek (Verde River Basin Partnership 2015, p. 12). The rate of groundwater discharge from Del Rio Springs has steadily decreased to about a tenth of its rate in the early 1940s, and the Arizona Department of Water Resources (ADWR) estimates that the discharge of groundwater from Del Rio Springs will cease by about 2025 (Nelson 2002, p. 25). The legacy and ongoing effect of groundwater use will continue to affect roundtail chub habitat through loss of connectivity within and between rivers because of diminished baseflow, which reduces habitat (*e.g.,* smaller pools, seasonally disconnects pools and riffles), and may increase competition and predation effects with nonnative fishes as habitat decreases (Haney *et al.* 2008, pp. 79-81; Ruhi *et al.* 2016, p. 469). Although much of the evidence used to support this argument is from the Verde River watershed, studies indicate that the effects of groundwater pumping occurred (and continue to occur) in rivers throughout the Lower Colorado River basin (Konikow 2013, p. 26). Many communities, agencies, and non-governmental organizations are working to reduce groundwater pumping and studying options for recharging aquifers, which may improve some riverine areas in the future (Nelson 2002, p. 26; Verde River Partnership 2015, entire; many others).

In summary, roundtail chub are sensitive to reduced flows due to modified natural hydrographs (Marks *et al.* 2009, p. 5) and although the mechanism is still not clear, late winter/early spring floods positively influence recruitment of young-of-year roundtail chub (Brouder 2001, p. 306-307). Therefore, we think that maintenance of a natural flow regime (Poff *et al.* 1997, p. 770) is important to roundtail chub persistence in the Lower Colorado River basin.

4.4 Land Uses

Large-scale disturbances from overgrazing, timber harvesting, poor road construction, and mining within watersheds and associated riparian areas in the 19th and 20th centuries, led to the degradation of riparian areas throughout the southwestern portion of the United States (DeBano and Schmidt 1989, p. 23; Meehan 1991, p. 2). Although these land uses likely had their greatest effects on roundtail chub and their habitats during that same period, there are legacy effects from these past actions that likely affect watershed function today (Nichols *et al.* 2018, p. 914). Current implementation of most livestock, timber, recreation, and mining activities include measures to protect aquatic species, water quality, and riparian vegetation (*e.g.*, USFS 2015a, pp. 14, 21-22, 44-45; USFS 2018a, pp. 29-31). A focus on improving watershed resiliency and function in the Lower Colorado River basin is resulting in improved watershed management and reduced population level effects from these land uses to roundtail chub (USFS 2018b, pp. 44-45). Below we briefly describe several land uses that have been identified as potential threats to the roundtail chub. This section, to the extent possible, uses information from the Lower Colorado River basin regarding these land uses.

4.4.1 Livestock Grazing

While research has not documented the effects of livestock grazing specifically on roundtail chub, widespread overgrazing degraded rangeland and altered watersheds throughout the Lower Colorado River basin starting in the late-1800s. Grazing can affect streams and rivers through a number of mechanisms including removal of riparian vegetation, reduced bank stability, increased bank erosion, and sedimentation, all of which can lead to loss of habitat (Propst 1999, p. 25; Voeltz 2002, pp. 23–88; Rees *et al.* 2005, p. 19). Earthen stock tanks created to water livestock can have both positive and negative effects for wildlife. Although stock tanks provide water and habitat to many native species, they also disrupt water delivery in drainages and often support nonnative aquatic species that can move into roundtail chub habitats during high flow events (Hedwall and Sponholtz 2005, p. 2).

Today, federal land management agencies closely regulate livestock management and private interest groups monitor the agencies for compliance with laws and regulations to provide protection and habitat improvement for selected areas (Jemison and Raish 2000, p. 555; Trudeau

2020, entire). Consequently, although many roundtail chub streams flow within active livestock grazing allotments, adverse effects from this action tend to be site-specific and land managers can address these site-specific effects by fencing riparian areas, altering pasture rotations, reducing ungulates (wild and domestic), and/or conducting physical habitat restoration (Rees *et al.* 2005, p.21). Therefore, we do not consider livestock grazing to be a population-level risk factor for roundtail chub.

4.4.2 Recreation

The overall effects of recreation on roundtail chub and associated habitat are largely unknown, but the level of effect likely depends upon the specific recreational activity. Activities such as hiking likely have little to no effect to roundtail chub, while those such as off-highway vehicle (OHV) use may have adverse effects to habitat (Ouren *et al.* 2007, pp. 6–22). The use of OHVs in and around streams may reduce vegetation cover and plant diversity, reduce infiltration rates, increase erosion, and reduce habitat connectivity (Ouren *et al.* 2007, pp. 6–22). For land managers, this has motivated the designing, construction, and maintenance of formal trail systems to reduce effects to aquatic ecosystems. The U.S. Forest Service and Bureau of Land Management either have travel management rules and education in place (*e.g.*, USFS 2012, entire) or are working on establishing them, with a stated purpose of removing trails that are currently contributing to sedimentation and/or other habitat effects. In addition, programs such as Tread Lightly® and the Arizona State OHV Ambassadors assist with educating recreationists on how to reduce their effects through instructional programs and training.

Sportfish angling, a popular recreational activity, may affect individual chub. Adverse effects of angling include, but are not limited to, direct catch and by-catch by anglers with the potential for hooking injuries. The AGFD has enacted statewide catch-and-release only angling regulations for roundtail chub, and some individual streams have received additional angling regulations (*e.g*., single barbless hooks only, artificial fly or lure only, etc.) to protect roundtail chub from these potential angling effects. Roundtail chub are a sportfish in Arizona and anglers do fish specifically for them, particularly in the Verde River (where anglers call them “Verde Trout”) and Fossil Creek. Fossil Creek has a special artificial lure and fly-fishing season featuring roundtail chub because anglers assisted federal and state agencies in removing nonnative fish from Fossil Creek, but in return wanted an opportunity to fish for them. Monitoring of the fish in Fossil Creek indicates there are no negative effects to the population from angling (Rinker *et al.* 2016, p.8) and Fossil Creek continues to support one of the most robust chub populations in Arizona (Rinker and Rogers 2020, p. 6).

We assume that in the future, the effects of recreation may increase and that these activities will continue to have effects to individual roundtail chub within site-specific areas. However, watershed protection is a key component of most watershed protection plans and recreational managers use infrastructure (*e.g*., signs, bathrooms, designated trails and campgrounds) to minimize the effects of people recreating, particularly near waters. It is likely there will continue to be some effects to individual chub because of recreational use; however, data do not indicate that recreation is having population level effects.

4.4.3 Mining

Recoverable minerals occur in the earth's crust from the surface to thousands of yards below ground, and mining engineers have developed an array of extraction techniques that they design based upon the location of the deposit (Nelson *et al.* 1991, p. 426). Arizona has a long history of metal mining and smelting. Starting in the mid-1800s, miners extracted copper, lead, zinc, silver and gold ore throughout Arizona (Arizona Geologic Society 2021). In 2020, there were 401 active, full-time mines or development projects in the state of Arizona (Richardson *et al.* 2020, p. 1). Approximately 84% of these active mines consisted of aggregate/crushed stone and building stone; cement/lime, cinders, gypsum, gemstones, metals, industrial metals, uranium, and smelters made up the remaining 16% of active mines (Richardson *et al.* 2020, p.1). The two broad categories of mining operations are: 1) surface mining, which includes all forms of open mines, strip mines, etc., that can be dredged or hydraulically mined; and 2) underground mining, which include operations below the surface in tunnels and shafts in which minerals are extracted by physical or chemical means (Nelson *et al.* 1991, p. 426).

Pollution of streams by acid mine drainage and increases in the background levels of metals following mining are both means by which mining operations can adversely affect fish (Nelson *et al.* 1991, pp. 429, 433). We are aware of a single roundtail chub population where the species (along with other native fish) completely disappeared from Mineral Creek, sometime between 2000 and 2002 (AGFD 2014a). Communications with Arizona Department of Environmental Quality (ADEQ)) about the potential source of discharge in Mineral Creek revealed that the Gibson Mine cleanup operations was the likely source of contaminated waters but could not be confirmed (AGFD 2011). There is mining, particularly aggregate mining (*e.g*., Verde River) and gold mining (*e.g*., Bill Williams River) occurring within other watersheds occupied by roundtail chub. Currently, we have no confirmed data to indicate that mining is having population level effects to roundtail chub, but there are likely site-specific effects in some areas.

Legacy mines (mines no longer in operation) cover the state of Arizona (ADEQ 2021). These mines can adversely affect waters by leaching metals into nearby streams and rivers. ADEQ classifies these waterways as 'impaired' when water quality exceeds Environmental Protection Agency (EPA) and Arizona standards. ADEQ is currently working on remediation of eight legacy mine sites to protect over 120 stream miles within the Hassayampa River (Bradshaw Mountains), Pinto Creek (Pinal Mountains), Alum Gulch (Patagonia Mountains), and Three R Canyon (Patagonia Mountains). None of these sites include known roundtail chub habitat.

4.4.4 Roads

Data do not indicate that roads are having population level effects to chubs. Poorly maintained roads in degraded watersheds can collect and channel stormwater runoff into streams, causing physical changes such as channel widening and downcutting. Typically, this scenario begins in a watershed or area devoid of plant cover with soil compaction. This loss of vegetation and soil compaction reduces infiltration and then roads and trails can concentrate and increase water and sediment delivery to channels (DeBano and Schmidt 1989, pp. 4-5). However, ongoing watershed management that maintains sufficient vegetative ground cover to slow overland flow and includes road maintenance (*e.g.*, culvert installation, installation of water bars) minimize the potential negative effects of roads to roundtail chub habitat.

4.4.5 Forest Management

National Forest System (NFS) lands include only 14 percent of the Arizona and New Mexico land base, but 40 percent of the surface and subsurface waters in the region originates on NFS lands administered by the Southwestern Region of the Forest Service (Baker *et al.* 1988, p. 47). A primary mission of the Forest Service is to protect the watersheds under its authority, consistent with the directives provided by Congress; however, overcutting occurred on Arizona and New Mexico National Forests when sawmills and nearby landowners dictated the demand for timber, rather than the age and condition of timber or other resource needs (Baker *et al.* 1988, p. 115). This resulted in overcutting of areas in the headwaters of many of the watersheds that support roundtail chub. Timber harvest can negatively affect long-term soil productivity if logging activities compact soils and may reduce water infiltration rates as well as other soil properties (Crawford *et al.* 2021, p. 9).

We did not find evidence that current forest management practices are negatively affecting roundtail chub populations. The focus of forest management in the Southwestern Region is to reduce fuels and focus mechanical harvest on small-diameter trees and conduct prescribed burning to minimize the potential for high intensity wildfire (see discussion below). The focus of this work is within watersheds occupied by roundtail chub, with the intent of improving watershed condition and forest function, particularly where perennial water occurs (*e.g.*, USFS 2015b, entire).

4.5 High Intensity Wildfire

In the southwestern United States, fire is a natural disturbance in montane watersheds that is necessary for ecosystem health and function and is integral to the forested ecosystems in the Lower Colorado River basin (Wright 1990 p. 1; Bowman *et al.* 2009, p.481). However, although historically wildfires have always occurred, they typically burned at much lower intensity prior to European settlement (Bowman *et al.* 2009, pp. 481-482). Past forest and land management activities (*e.g*., fire suppression, logging practices, excessive livestock grazing), have resulted in increases in the size, frequency, and severity of fires as fire was removed from the landscape and fuels have accumulated (Covington and Moore 1994, p. 40). In addition, the drier, warmer regional climate has resulted in increased spring and summer temperatures and earlier spring snowmelt, which has resulted in more extreme fire behavior (Werth *et al.* 2011, pp. 25-27; Westerling 2016, pp. 8-9). The frequency and duration of drought are increasing in this region, further influencing the frequency of wildfire (Garfin *et al.* 2014, p. 463). However, management efforts to conduct forest thinning and fuels reduction within the Lower Colorado River basin are on-going (*e.g*., USFS 2015b, entire).

There are streams occupied by roundtail chub in watersheds where high intensity fires affected watershed condition (e.g., Eagle Creek, Silver Creek, and Sabino Canyon). Following the Cave Creek Complex Fire (2005) and Wallow Fire (2011), substantial reductions in roundtail chub populations in Silver Creek and Eagle Creek occurred from post-fire events (Sitzmann 2017, pp.

5-6; Clarkson *et al.* 2012, p. 3). After forest fires, the potential for flooding and erosion dramatically increases, partially due to decreased infiltration across the burned landscape (Robichaud *et al.* 2008, pp. 1-2). In a worst-case scenario, post-fire effects can result in subsequent flood events, stream channel changes, riparian habitat effects, and significantly decreased water quality that can make streams unsuitable for fish years following the fire (Rinne and Carter 2008, p. 171; Rieman *et al*. 2012, p. 164). Roundtail chub in Silver Creek are still reduced in numbers compared to pre-fire estimates, but the Eagle Creek population has recently improved (Appendix E, Tables E-2 and E-6).

We have no information to indicate that wildfires have resulted in documented extirpations of chub populations in the past 20 years, even with increasing fire size and intensity across the landscape. However, large, high-intensity wildfires will continue to occur as described above. Therefore, reducing the risk of fire occurring at high intensity over large areas is a management emphasis many are taking to reduce risk to all watersheds. Land managers are making efforts to reduce fire risks, particularly with landscape level forest restoration projects, such as the Four Forest Restoration Initiative (4FRI), Phase 1 (USFS 2015b, entire), 4FRI Rim Country Project (in draft), Hassayampa Landscape Scale Restoration Project (USFS 2019, entire), as well as many other projects.

4.6 Disease and Pathogens

Nonnative parasites such as Asian tapeworm (*Bothriocephalus acheilognathi*), anchor worm (*Lernaea spp*.), and Ich (*Ichthyophthirius multifiliis*) are found within the Lower Colorado River basin and infect individual roundtail chub. These parasites and others, such as black and yellow grub (*Uvulifer ambloplitis* and *Clinostomum complanatum*), likely occur throughout the range of the species. While the current level of exposure to these parasites does not appear to have resulted in extirpations or population declines, there are effects to individuals particularly when fish become isolated in pools during the warmest times of the year (Rottmann *et al*. 1992, p. 1).

4.7 Climate Change

Ongoing monitoring and projections indicate that climate change will increase aridity across the already drought-affected landscapes of the Lower Colorado River basin (Seager *et al.* 2013, p. 482; Garfin *et al*. 2014, p. 464).). Some studies suggest strong seasonal signatures will result in increasing winter precipitation and streamflow (especially in northern latitudes) and decreasing late summer and fall precipitation and streamflow (especially in southern latitudes) because of climate change (Milly *et al.* 2005, p. 347; Das *et al.* 2011, p. 4). In arid and semiarid regions in the western U.S., where intermittent streams are common, several studies predict that minimum flows will decrease, and the number of zero-flow days will increase in the future (Das *et al.* 2011, p. 4; Leppi *et al.* 2012, p. 1012; Jaeger *et al.* 2014, p. 13895). Decreased minimum flows could cause some perennial streams to shift to intermittent streamflow regimes under climate-driven changes in timing and magnitude of precipitation and runoff and increases in temperature (Jaeger *et al.* 2014, p. 13894). However, Robles *et al.* (2021, pp. 11-12, 19) found that in the Salt River basin, a shift towards more winter streamflow generation may increase total streamflow because of warmer winters (more rain, less snow) during seasonally lower periods of potential evapotranspiration. Additionally, an increase in extreme precipitation events and more rain (versus snow) at higher elevations may increase the frequency and intensity of winter flooding (Robles *et al.* 2021, p. 19). Besides the uncertainty regarding modeled persistence of streamflow and what will occur with late winter/spring floods within the Lower Colorado River basin, additional factors such as changes in water management, adjudication of unresolved water rights and water use policy will likely also affect future streamflow (Garfin *et al.* 2014, p. 483).

Decreased streamflow may affect roundtail chub by reducing habitat within streams (*e.g.*, disconnecting pools, reduced riffle habitats, reduced stream length) which may also increase competition and predation effects from nonnative fishes (Haney *et al.* 2008, pp. 79-81; Ruhi *et al.* 2016, p. 469). We are uncertain how a potential shift from late winter/spring floods to late fall/early winter will affect chub recruitment. However, data indicate that streams with essentially natural flow regimes (*i.e.*, West Clear Creek) have decreasing mean annual flow because of climate change (Ruhi *et al.* 2016, pp. 470). We anticipate there will be variation among watersheds regarding how climate change affects individual streams over the next several years. However, confidence is high that warmer temperatures during periods of greater evapotranspiration and reduced soil moisture in the warm seasons will likely diminish streamflow, reduce the length and distribution of habitats (*e.g.*, disconnect pools) and result in changed habitat conditions and biological cues for roundtail chub (Garfin *et al.* 2014, p. 483; Crimmins and Crimmins 2019, pp. 12384-12385). We anticipate that these changes are likely to have negative population level effects to roundtail chub.

4.8 Summary of Risk Factors

The singular and synergistic effects of “high effect” nonnative fishes, reductions in streamflow, which includes diminished flow, less habitat, and potentially shorter wetter sections, and climate change are the risk factors most likely to result in population level effects to roundtail chub. If these factors reduce the ecological integrity of chub streams and result in scattered, small, and disjunct populations, without the means to naturally recolonize, this will weaken the species resiliency, which ultimately increases the risk of individual populations becoming extirpated (Fagan *et al.* 2002, pp. 3254–3255). Although the other risk factors may be issues for these small, stressed populations, land uses, and even high intensity wildfire are not currently having the greatest negative effect on roundtail chub persistence in the Lower Colorado River basin. The ongoing efforts to maintain, enhance and create additional chub populations with relatively independent susceptibility to these risk factors will be an important consideration in the long-term viability of this species (Shaffer 1981, entire; Goodman 1987, entire). Redundant populations will also provide security from stochastic events or repeated recruitment failure.

4.9 Conservation Actions

Conservation actions (augmentations, new introductions, reintroductions, range expansions, nonnative removal efforts, habitat restoration, etc.) for roundtail chub in the Lower Colorado River basin can positively influence population resiliency and species redundancy and representation. Here we discuss ongoing conservation actions for roundtail chub.

There are two large-scale conservation agreements in place that benefit roundtail chub in the Lower Colorado River basin. The first agreement is the Range-Wide Conservation Agreement and Strategy for Roundtail Chub *Gila robusta*, Bluehead Sucker *Catostomus discobolus*, and Flannelmouth Sucker *Catostomus latipinnis* (hereafter referred to as the “3 Species Agreement”) (Colorado River Fish and Wildlife Council 2006, entire). Signatories to the 3 Species Agreement (Signatories) include the AGFD, Bureau of Land Management (BLM) - Colorado, BLM – New Mexico, BLM – Utah, BLM – Wyoming, National Park Service – Intermountain Region, U.S. Bureau of Reclamation – Upper Colorado Region, Colorado Division of Parks and Wildlife, Idaho Department of Fish and Game, the Jicarilla Apache Nation, Nevada Department of Wildlife, NMGFD, Southern Ute Indian Tribe, U.S. Fish and Wildlife Service (USFWS) – Legacy Region 6, USFWS – Legacy Region 2, U.S. Forest Service – Intermountain Region, Utah Division of Wildlife Resources, and the Wyoming Game and Fish Department. The other agreement currently in place is the Arizona Statewide Conservation Plan for Roundtail Chub (*Gila robusta*), Flannelmouth Sucker (*Catostomus latipinnis*), Little Colorado River Sucker (*Catostomus* spp.), Bluehead Sucker (*Catostomus discobolus*), and Zuni Bluehead Sucker (*Catostomus discobolus yarrowi*) (Hereafter referred to as the “5 Species Agreement”) (AGFD 2021, entire). Signatories to the 5 Species Agreement include the ADWR, AGFD, Arizona State Land Department, BLM - Arizona, Bureau of Reclamation (Reclamation), Hualapai Tribe, National Park Service – Intermountain Region, The Nature Conservancy, Salt River Project, USFWS – Legacy Region 2, and the U.S. Forest Service – Southwest Region 3. The final signed 3 Species Agreement has been in place since 2006 (management efforts began in 2004), and previous versions of the 5 Species Agreement have been in place since 2007. Both documents have goals of ensuring the persistence and conservation of roundtail chub. The objectives for the two documents are very similar and can be summarized as follows: 1) develop and finalize a conservation strategy that provides goals, objectives, and conservation actions that serve as guidelines for the development and implementation of individual state wildlife management; 2) establish measurable criteria to evaluate the number of populations and numbers of individuals within populations to ensure the continued persistence of roundtail chub; 3) establish or maintain sufficient connectivity so that viable metapopulations are established and/or maintained; and 4) identify and significantly reduce and/or eliminate threats that may warrant or maintain their listing as a sensitive species by state and federal agencies and that may warrant their listing as a threatened or endangered species under the ESA.

Signatories to both agreements have developed and finalized conservation strategies that guide the development and implementation of conservation actions for roundtail chub. For simplicity we focus only on those conservation actions as defined in the implementing document for the 3 Species Agreement, which is called the 3 Species Conservation Agreement Strategy (Colorado Fish and Wildlife Council 2019, pp. 48-51); however, many of the actions described in the 5 Species Agreement are similar. The 3 Species Conservation Agreement Strategy defines nine conservation actions used in the conservation of roundtail chub; 1) Conduct status assessments of roundtail chub; 2) Establish and maintain a range-wide database of current and historic information on roundtail chub; 3) Determine roundtail chub population demographics, life history, habitat requirements, and conservation needs; 4) Maintain diversity of roundtail chub; 5) Maintain or expand possible roundtail chub distribution and abundance; 6) Maintain, enhance, and evaluate habitat for roundtail chub; 7) Address (as feasible and where possible) threats posed by nonnative species that compete with, prey upon, or hybridize with roundtail chub; 8) Establish and implement long-term population monitoring programs for roundtail chub; and 9) Implement outreach activities (e.g., development of partnerships, information, and education activities) regarding conservation and management of roundtail chub. All conservation actions implemented since 2004 that fall under the actions defined above are discussed in detail below.

4.9.1 Conduct status assessments

Under the 3 Species Agreement, the Signatories complete status assessments for roundtail chub every ten years. In addition, the Signatories complete their own species status assessments when needed. For example, the AGFD completed a status assessment of roundtail chub in the Lower Colorado River basin in 2014 (Jones et al. 2014, entire), with previous assessments completed by Voeltz (2002, entire), and Weedman et al. (1996, entire). The AGFD uses these assessments to evaluate progress toward conservation objectives and aid in prioritizing management efforts.

4.9.2 Establish and maintain a database

The 3 Species Team established a 3 Species Rangewide geospatial database in 2020 (3 Species Rangewide Conservation Team 2020). This database contains estimates of historically occupied ranges, current distribution of roundtail chub, defined populations and their status, population demographics, nonnative species distribution and abundance, and conservation actions for roundtail chub. The Signatories maintain and update the database at regular intervals (RTC Protocol, p. 1). The database is used to aid in meeting 3 Species Agreement objectives and in completing status assessments for roundtail chub.

4.9.3 Determine population demographics, life history, habitat requirements, and conservation needs

The 3 Species Team identified that the population demographics, life history, habitat requirements and conservation needs of these species have historically been a critical information gap. To date, research of roundtail chub population demographics (Brouder 2005, entire), captive propagation techniques (Bonar *et al.* 2011, entire; Shultz and Bonar 2016, entire), life history needs (Brouder *et al.* 2006, entire; Schultz and Bonar 2006, entire), habitat use (Bonar *et al.* 2010, entire; Jenney 2020, entire) and conservation needs (Hickerson *et al.* 2021, entire) have been completed under the auspices of the 3 Species Team. This research has helped to improve the conservation status of roundtail chub within the Lower Colorado River basin.

4.9.4 Maintain Diversity

Researchers completed or are conducting multiple studies to better understand the genetic and morphological characteristics of roundtail chub in the Lower Colorado River basin with the goal of informing conservation efforts. These studies included Dowling *et al*. (2008, entire), Dowling and Schwemm (2008, entire), Carter *et al.* (2018, entire), Copus *et al.* (2018, entire), and Chafin *et al*. (2021). An increased understanding of genetic and morphological characteristics for roundtail chub in the Lower Colorado River basin will inform management plans and proper management of genetic diversity of roundtail chub in the Lower Colorado River basin.

4.9.5 Maintain or, wherever possible, expand, distribution and abundance

Managers have expanded the distribution of the roundtail chub through reintroduction to previously occupied habitats, translocation to unoccupied habitats without historical records, and creation of refuge populations. AGFD and NMDGF typically conduct wild-to-wild stockings with fish from within the stream or the closest appropriate population. Hatcheries also support these efforts through the maintenance and propagation of specific lineages of roundtail chub in hatcheries or refuge ponds, which AGFD may also use for establishing or augmenting wild populations within the same watershed and/or genetic lineage of chub. The AGFD currently maintains a broodstock of both Verde River lineage and Eagle Creek lineage roundtail chub at its Bubbling Ponds and Aquatic Research and Conservation Center facilities. In addition, roundtail chub currently occupy 12 refuge ponds in Arizona (AGFD, unpublished data). The AGFD uses these fish to augment the original source population, if needed. More commonly, managers collect chub from a wild donor location and directly translocate the chub to recipient waters. Fisheries biologists choose donor locations in cooperation with partner agencies and with consideration of appropriate lineages for the recipient watershed. Since initiation of the 3 Species Agreement in 2004, 20 populations of roundtail chub have been introduced, reintroduced, or expanded within the Lower Colorado River basin (Table 4-2, Appendix B). In addition to expanding population distributions, managers have increased populations of roundtail chub through augmentation of existing populations with roundtail chub collected from captive or wild locations. Since 2004, at least 37 augmentations in 14 streams have occurred at locations occupied by roundtail chub to increase population sizes and aid in population establishment and persistence (Table 4-2, Appendix B). Reclamation's Gila River Basin Native Fish Conservation Program (GRBNFCP) funds augmentations and reintroductions conducted by AGFD and NMDGF are. The GRBNFCP also provides funding that directly supports augmentation and reintroductions efforts and provides funding to maintain roundtail chub rearing at the AGFD Bubbling Ponds and Aquatic Research and Conservation Center facility.

4.9.6 Maintain, enhance, and evaluate habitat

Enhancement and maintenance of roundtail chub habitat through the creation and maintenance of fish passage barriers, which prevent the upstream movement of nonnative fishes and allow for removal of nonnative fishes from reaches upstream of barriers (See 4.8.7). Since 2004 Reclamation has constructed six barriers as part of the Central Arizona Project that benefited roundtail chub populations (USBR 2019, entire). In addition to building barriers, the AGFD and partners complete habitat evaluations at locations that may provide suitable habitat for roundtail chub or are recovering from stochastic events such as wildfire. Habitat evaluations can vary depending on the site and the signatory conducting the evaluation. Simple habitat evaluations may only involve mapping the extent of perennial water during the driest time of the year. While more in-depth evaluations may collect information on the proportion of pool habitat, maximum pool depth, pool tail depth, wetted width, stream depth, substrate composition, substrate embeddedness, water velocity, canopy cover, and instream cover. Since 2004, AGFD completed at least 50 habitat evaluations for roundtail chub (AGFD 2014b, pp. 3-5; AGFD 2015, p. 2-4; AGFD 2016 pp.2-4; AGFD 2017 pp. 2-5; AGFD 2018 pp. 3, 6-7; AGFD 2019, pp. 3, 5-6; AGFD 2020, p. 4). The GRBNFCP also provides funding that directly supports monitoring activities in Arizona and New Mexico.

4.9.7 Address threat posed by nonnative species

Control of nonnative species to benefit roundtail chub in the Lower Colorado River Basin is primarily done using standard sampling gears, such as backpack electrofishing, to collect and remove nonnative species (commonly referred to as mechanical removal) or by using piscicides (*e.g.*, rotenone). Piscicides are typically more effective at ensuring complete eradication, but it can be difficult to obtain proper approvals for use in certain locations. While mechanical removal, particularly through electrofishing, is generally easy to implement, it is most effective in small streams with simple habitat (Meyer *et al.* 2006, pp. 849-850, 858). This can create problems when trying to eradicate nonnative fish from streams with more complex habitat as it is extremely important to achieve complete eradication; failure to do so can allow nonnative populations to reestablish themselves (Finlayson *et al.* 2005, entire; Meyer *et al.* 2006, entire). Since initiation of the 3 Species Agreement, nonnative removal efforts have been initiated in 14 streams, followed by 7 complete removals, occupied by roundtail chub (Table 4-2, Appendix B). Often, managers have built artificial barriers to fish passage prior to removing nonnative species. These barriers prevent the recolonization of upstream habitat by nonnatives.

4.9.8 Establish and implement population monitoring

A number of programs, including the GRBNFCP, AGFD's Native Trout and Chub and Regional Fisheries Programs, Bureau of Land Management, U.S. Forest Service and U.S. Fish and Wildlife Service, conduct monitoring of roundtail chub populations within the Lower Colorado River basin in Arizona. AGFD established a monitoring plan that schedules monitoring efforts for 75 roundtail chub localities to ensure that monitoring of nearly all extant populations occurs on a regular basis for the next 10 years (AGFD, unpublished data). Additionally, Reclamation's most recent monitoring report states they are conducting/funding monitoring of roundtail chub at 26 localities throughout Arizona and New Mexico (Shollenberger *et al.* 2021, entire). The mitigation commitment from Reclamation is to monitor native fish in the Gila River basin for the 100-year life of the Central Arizona Project (CAP) canal. This monitoring plan ensures that surveys of populations will occur on regular intervals and enables managers to identify problems and take actions to address issues as they arise.

The NMDGF, Bureau of Land Management, U.S. Fish and Wildlife Service, and U.S. Forest Service conduct monitoring of roundtail chub in the Lower Colorado River basin in New Mexico. They conduct monitoring annually at several permanent sites in the Gila River and San Francisco River basins. Other locations where fisheries managers know or expect roundtail chub to occur, they sample on a ten-year rotating basis. Managers sample recently reintroduced populations for five consecutive years after reintroduction and then every five years thereafter.

4.9.9 Implement outreach activities (*e.g*., develop partnerships, information, and education activities)

Outreach activities can aid conservation efforts through educating the public about the conservation needs of native fish species and increasing support for conservation actions that benefit native species. The majority of outreach activities for roundtail chub have been through the publication of popular articles primarily in Arizona Wildlife Views, or the various media outlets of the AGFD. Other outreach efforts used to educate the public include posters, bookmarks, and key chains.

Table 4-2: The total number of augmentations (A), new introductions (I), reintroductions (R), range expansions (RE), active nonnative removal efforts, and completed nonnative removal efforts for roundtail chub in the Lower Colorado River basin from 2004 to 2020. For a complete list of stream names associated with Table 4-2, see Appendix B.

HUC06 Watershed	Stream Name	Number of introductions, reintroductions, and range expansions	Number of augmentations	Number of nonnative removal efforts conducted	Number of nonnative removals completed
Bill Williams River	Bill Williams River	1 (RE)	0	0	0
Bill Williams River	Bill Williams River (Private Land)	2 (I), 2 RE	5 (A)	10	2
Lower Gila-Agua Fria River	Hassayampa River (Private Land)	1 (I)	1 (A)	0	0
Lower Gila-Agua Fria River	Lower Gila River Pond	1 (I)	0	0	0
Lower Gila-Agua Fria River	Indian Creek	0	0	2	0
Salt River	Ash Creek	1 (I)	2	0	0
Salt River	Willow Springs Lake	0	0	9	0
San Pedro River	Redfield Canyon	0	0	14	0
San Pedro River	San Pedro River Private Land	1 (I)	1 (A)	0	0
Santa Cruz River	Bear Canyon	1 (I)	0	0	0
Santa Cruz River	Romero Canyon	1 (I), 1 (RE)	0	0	0
Santa Cruz River	Sabino Creek	1 (I)	0	0	0

HUC06 Watershed	Stream Name	Number of introductions, reintroductions, and range expansions	Number of augmentations	Number of nonnative removal efforts conducted	Number of nonnative removals completed
Santa Cruz River	Santa Cruz River (Private Land)	5 (I)	3 (A)	0	0
Santa Cruz River	Sweetwater Dam	0	0	1	1
Upper Gila River	Blue River	1 (I), 1 (RE)	2 (A)	9	0
Upper Gila River	Blue River (Bobcat Flat)	1 (RE)	0	0	0
Upper Gila River	Bonita Creek	0	0	3	1
Upper Gila River	Harden Cienega Creek	1 (RE)	1 (A)	1	0
Upper Gila River	Mule Creek	1 (I)	2 (A)	0	0
Upper Gila River	West Fork Gila River	0	0	15	0
Verde River	Fossil Creek	1 (R)	0	3	2
Verde River	Gap Creek	1 (I)	2 (A)	0	0
Verde River	Oak Creek	0	5 (A)	0	0
Verde River	Rarick Canyon	1 (I), 1 (RE)	1 (A)	2	1
Verde River	Red Tank Draw	0	0	5	0
Verde River	Roundtree Canyon	1 (I)	4 (A)	0	0
Verde River	Spring Creek	0	0	5	1
Verde River	Verde River	0	4 (A)	0	0
Verde River	Verde River (Private Land)	7 (I)	5 (A)	3	2
Verde River	Webber Creek	1 (R)	1 (A)	0	0

5 CURRENT CONDITION

5.1 Overview

Among the variables collected for the 3-Species Rangewide geospatial database (hereafter "Database") are the historically and currently occupied streams. The Database represents the best available information on the distribution of roundtail chub, and we used it to inform our SSA. In assessing the status of roundtail chub in the Lower Colorado River basin, we considered several metrics that we think are critical to the species persistence. First, using the Database, we compared the historical and current distribution of the species. Due the nature of the historical data, we could only compare occupied stream length across the Lower Colorado River basin to current occupancy, as opposed to more detailed information on variables such as changes in abundance, number of populations, genetic diversity, and temporal changes in stressors. However, we think that comparing historical and current distribution will reflect qualitative changes in resiliency, redundancy, and representation. Based on our overview of viability (Chapter 3), for roundtail chub to persist they require complex habitat, sufficient in quantity and quality and distributed across a range of watersheds and ecological conditions to minimize the overall effect of stochastic and catastrophic events and maximize potential adaption to changing environmental conditions. Comparing historical and current distributions would provide context to assess the species viability.

There are also more detailed data regarding the status of roundtail chub populations. The Database contains data on a range of variables relevant to the status of roundtail chub. For our SSA, we chose to assess current conditions based on variables that reflect factors and stressors identified in Chapters 3 and 4, respectively, as being important for roundtail chub viability. Populations that occupy longer stream lengths may be more likely to support abundant populations, have more connections to populations in tributary streams and thus have increased resilience to stochastic events and potential catastrophes, as well as interact with habitats that are more diverse. They are also more likely to support higher levels of genetic diversity. Thus, we used occupied stream length as a metric to assess status of roundtail chub populations. The Database also records recent population trends and recruitment in individual stream segments. We developed a system to categorize populations based upon whether field data suggest changes in abundance and age structure. Finally, given the effect of non-native species on roundtail chub, we also ranked non-native communities that co-occur with roundtail chub based on species composition.

5.2 Analysis Area

As noted, this SSA is focusing on the status of roundtail chub in the Lower Colorado River basin. Traditionally, the demarcation between the lower and upper Colorado River basins is Glen Canyon Dam, as per the Colorado River Compact, the 1922 agreement among seven U.S. states in the basin of the Colorado River in the American Southwest that governs the allocation of the water rights to the river's water among the parties of the interstate compact (Appendix C). By this definition, the lower basin would include three watersheds where roundtail chub are currently present: the Little Colorado River, Bill Williams River, and Gila River. For this SSA, we only considered the Bill Williams and Gila River watersheds in our assessment of the species.

We provide a more detailed rationale for not including the streams from the Little Colorado River as part of this SSA in Appendix C.

5.3 Historical and Current Distribution

For the historical distribution, species experts estimated occupied streams lengths contributing to the Database. The criteria were locations that roundtail chub may have occupied at the time of the first European exploration of the Pacific Northwest (circa 1800) (RTC Protocol p. 2). We based this on expert judgement on suitable areas (known or presumed presence of water) where roundtail chub may have occurred. These criteria likely result in an overestimate of potential historical distribution due to the uncertainty around historical perennial stream length and distribution of roundtail chub. Consequently, many streams included in the potential historical distribution are not associated with any known records of roundtail chub (Appendix D). In addition, some of these streams may not have supported self-sustaining populations, but instead connected to self-sustaining roundtail chub populations and received dispersing individuals. Regardless, the expert judgement included in the Database represents the most robust available data on the potential historical distribution of roundtail chub. From this output, the estimated historical distribution covered 5,468 km distributed across nine HUC6 watersheds (Figure 5-1; Table 5-1). Almost 60% of this potential historical distribution was within three HUC6 watersheds: the Salt, the Upper Gila, and the Verde watersheds (Appendix E, Figures 5-2-8).

We based current distribution upon the streams currently occupied by roundtail chub using the criteria identified in the Database (see section 5.4). We report this in terms of absolute stream length considered occupied regardless of the status of the population. The currently occupied stream length represents an approximate 66% reduction in the species distribution compared to the potential historical distribution (Table 5-1). Roundtail chub are extirpated from two HUC6 watersheds where they historically occurred (the Middle and Lower Gila watersheds) and have experienced potential range reductions greater than 80% in three others (Lower Gila-Agua Fria, San Pedro-Wilcox, and Santa Cruz watersheds). The Bill Williams River watershed has experienced the smallest reduction in occupied range compared to the potential historical distribution (12%).

Table 5-1: Historical and current total estimated occupied stream lengths for roundtail chub in the Lower Colorado River basin. Total and per HUC6 watershed values are presented along with changes in values between the historical and current distributions. Note that the historical totals represent the potential historical range based upon expert judgement.

Watershed HUC6 unit	Historically occupied stream length (km)	Currently occupied stream length (km)	Decline in occupancy (km)	Decline in occupancy (%)
Bill Williams	366	322	44	12
Lower Gila	202	0	202	100
Lower Gila-Agua Fria	402	22	380	95
Middle Gila	272	0	272	100
Salt	1216	477	739	61
San Pedro-Wilcox	560	66	494	88
Santa Cruz	415	24	391	94
Upper Gila	1208	382	827	68
Verde	827	552	275	33
Total	5468	1845	3623	66

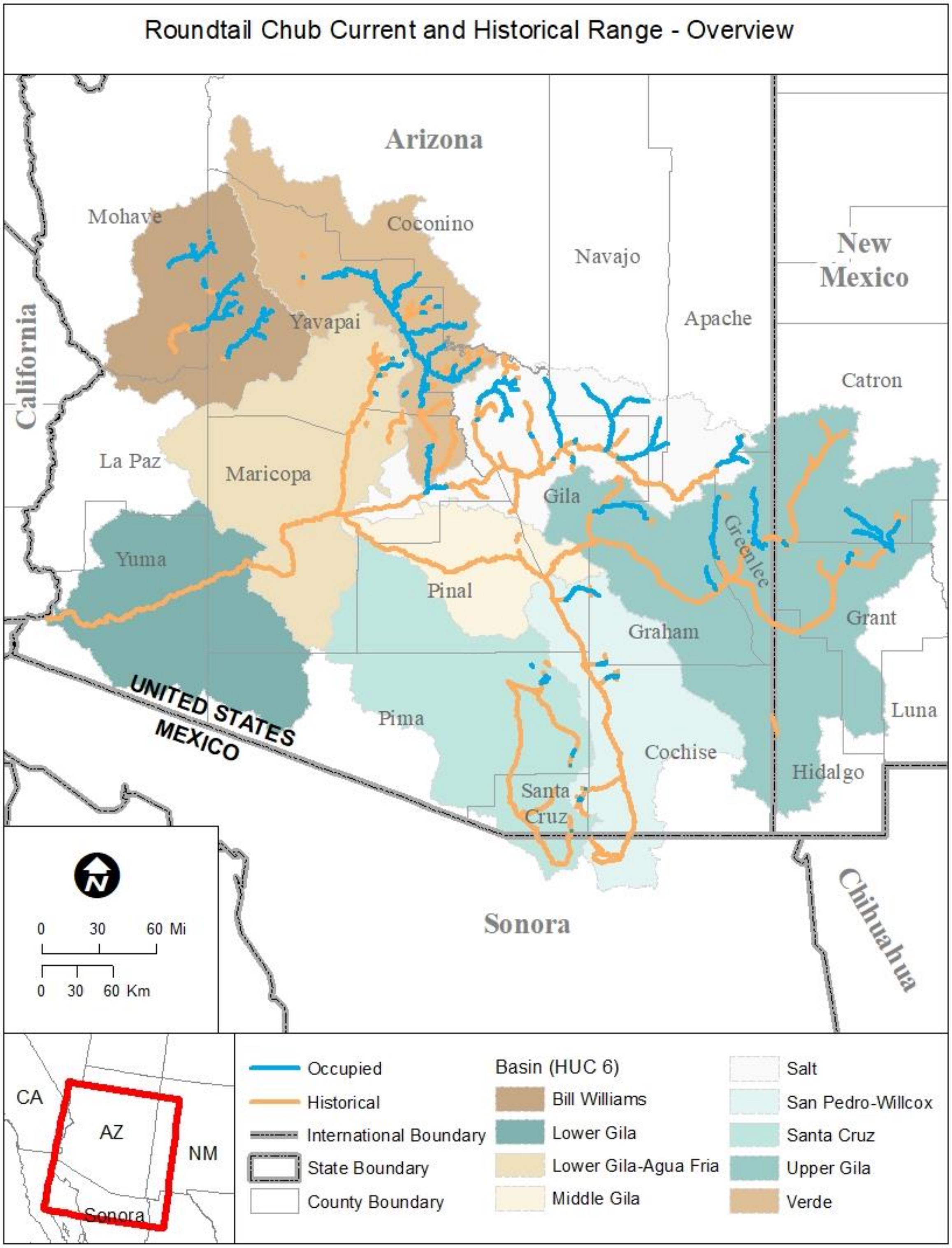

Figure 5-1: Map of the historical and current occupied range of roundtail chub in the Lower Colorado River basin based on the 3-Species Rangewide geospatial database.

5.4 Methodology for Assessing Extant Populations

In the Lower Colorado River basin, roundtail chub occur in seven primary rivers: the Bill Williams, Lower Gila-Agua Fria, Salt, San Pedro, Santa Cruz, Upper Gila, and Verde in Arizona and New Mexico. Within these HUC6 watersheds, roundtail chub exhibit a complex population structure. Historically, interconnected streams with suitable habitat supported roundtail chub movement between metapopulations. However, natural barriers, such as waterfalls, isolated some populations. Currently, alterations to the watersheds, such as dams, have isolated additional populations, and some populations are periodically isolated due to seasonal events such as stream dewatering. This creates a mosaic of populations across the basin. To capture this diversity and complexity, the Three Species Conservation Working Group developed a protocol (hereafter "Protocol") (Final Version 11/13/2019) to characterize streams occupied by roundtail chub and assess their interconnectedness. The following paragraphs describe how we used the Protocol/Database to inform the SSA.

There are three population categories used to populate the database: current population, assumed present, and extirpated. To establish current conditions for roundtail chub, fisheries staff from the AGFD and NMGFD identified segments of a stream that are currently occupied (since 2004). These segments are defined in the Database as population mapping units (PMU). PMUs were attributed with available survey information, including recorded life stages, relative abundance, presence of nonnatives, and conservation actions. A population can be composed of multiple PMUs: the delineation of PMUs reflects breakpoints in streams due to the presence of features such as barriers that could significantly influence roundtail chub distribution, life history expression, and spawning or competition (RTC Protocol, p. 19-20). Where this occurs, we used a numbering system, beginning with one, to identify the furthest upstream PMU and continued numbering downstream (See Appendix E). For each PMU, relative abundance estimates were recorded for each life history stage of roundtail chub (larval, Age-0, Juvenile, Adult). Where relative abundance (*i.e.*, catch per unit effort [CPUE]) information was available, each life stage was classified as low, medium, or high for a particular gear type at each PMU. For life stages where relative abundance was not available, we categorized life stages as "known or probable absence" or "known presence – density not estimated" (RTC Protocol, p. 16-19). We categorized a PMU as *assumed present* if surveys last detected chub ten or more years ago but there is no recent information available to suggest that the population has been extirpated. We categorized a PMU as *extirpated* if surveys have not detected in the past 50 years. This definition was adapted from the definition of *extinct* adopted by the American Fisheries Society (AFS; Jelks *et al.* 2008, p. 375), which refers to a taxon (*e.g.*, species) of which no living individual has been documented in its natural habitat for 50 or more years. However, because the sampling effort involved in detecting the presence of a rare species within a wide and complex distribution can be much greater than for a single population with a restricted and simple distribution, we have defined several instances where the 50-year detection criterion may be relaxed when declaring a population extirpated: (1) the population has not been detected in the past 50 years; (2) the population has not been detected in presence/absence surveys conducted expansively (across the entire distribution of the population), intensively (sampling all suitable habitats), and effectively (suitable habitats were sampled with appropriate gears) over a minimum period of ten consecutive years or ten surveys in total if not sampled in consecutive years; (3) a known catastrophic event such as a chemical spill, wildfire, or desiccation occurred that eliminated the population. In this case, a single expansive survey of the population range post-event would be sufficient to conclude extirpation; or (4) managers intentionally removed the population from the wild and placed it into managed refuges in an attempt to salvage its genetic legacy in the face of severe population decline and apparent imminent extirpation (RTC Protocol, pp. 3-4).

Once we generated all of the PMUs in the database, we identified populations following the procedures defined in the protocol. A population, as defined in the Protocol, needs to support all roundtail chub life stages, is able to exist independent of other populations, and is not divided by complete barriers. Populations may have one or more PMUs as long as they are contiguous, allow for movement, and have the capability of gene transfer in all directions (RTC Protocol, p. 3). For example, one of the Verde River populations (cp0042), has 20 PMUs, and is 428 km in length (See Appendix E).

We assigned overall population stability rankings in the Database using available information collected by AGFD and NMDFG over the last ten-year period. There are five population stability rankings in the protocol. We combined the first two rankings for our SSA because they both were similar and merging the two did not affect the stability ranking criteria. The revised population stability is ranked in the following four categories (Table 5-2). There are a few instances where a PMU did not qualify as a population because we did not know if all life stages were present. In these cases, we did not assign the PMU a population stability ranking in the database.

Table 5-2: Revised population stability rankings.

Code	**Population Stability**
1	Roundtail chub are present, recruitment is occurring, and the population is stable or increasing.
2	Roundtail chub are present, but recruitment may be limited.
3	Roundtail chub are present but declining, and there is limited reproduction and/or recruitment.
4	Unknown over the period.
N/A	No life stages are present.

5.5 Status of Extant Populations

The following roundtail chub current condition discussion is a summary of population stability within the Lower Colorado River basin. For a complete breakdown of each population within a HUC6 watershed see the tables in Appendix E. It is important to note we made some changes to the population stability scores compared to the Database. As we were evaluating information from the Database we identified a few areas where the population stability categories did not match our current knowledge of a PMU or population. Where this occurred, we asked AGFD and NMDGF for additional information to support or change the stability ranks for the SSA. Within the seven occupied watersheds in the Lower Colorado River basin, we have identified 83 populations and 161 PMUs totaling 1,845 km of stream (Table 5-3; Appendix E).

Table 5-3: Summary of occupied stream length, number of populations and number of PMUs by Watershed (HUC6).

HUC6 Watershed	Occupied Stream (km)	Number of Populations	Number of Population Mapping Units
Bill Williams	322	12	29
Lower Gila	0	0	0
Lower Gila-Agua Fria	22	5	8
Middle Gila	0	0	0
Salt	477	13	27
San Pedro-Wilcox	66	8	16
Santa Cruz	24	10	12
Upper Gila	382	15	30
Verde	552	20	39
Total	**1,845**	**83**	**161**

We considered most of the occupied PMUs (80%) to be stable or increasing with documented recruitment (Table 5-4). There was some variability across HUCs, with the lowest proportion at 67% (Upper Gila). Only 2% of the occupied range contains roundtail chub populations that were reported to have documented declines (Category 3, Table 5-4).

Table 5-4: Number of PMUs that reported each population stability category grouped by watershed (HUC6). Note that this does not include the Lower Gila and Middle Gila HUCs, as roundtail chub are extirpated from these HUCs.

HUC6 Watershed	1	2	3	4	N/A
Bill Williams	27	0	0	2	0
Lower Gila-Agua Fria	6	0	1	1	0
Salt	22	0	1	3	1
San Pedro	15	0	0	1	0
Santa Cruz	10	0	0	1	1
Upper Gila	20	2	0	2	6
Verde	29	1	1	5	3
Total	**129**	**3**	**3**	**15**	**11**

5.6 Nonnative communities

Based on our review of threats, we also wanted to assess populations based upon the nonnative communities that co-occur with roundtail chubs. We recorded the occurrence of nonnative species at the PMU-level in the Database. We developed categories for nonnative communities based on their effect on roundtail chub (Table 5-5).

Table 5-5: Nonnative species effect categories.

Level of Effect to Chub	Nonnative Species Category
High	Green sunfish, flathead catfish, smallmouth bass, largemouth bass. High effect means these nonnative species can substantially affect chub populations through reduced recruitment and persistence resulting from predation, competition, and displacement.
Medium	Rock bass, channel catfish, black bullhead, yellow bullhead, red shiner, brown trout. Moderate effect means these nonnative species mainly affect chub populations through displacement and competition for food resources.
Low	Common carp, fathead minnow, rainbow trout, western mosquitofish, crayfish, bullfrog. Low effect means these nonnative species may affect an individual chub through competition and/or predation, but they have less of an effect to chub populations.

We then assigned qualitative and numerical values for PMUs that have high, medium, low, or no nonnative species (Table 5-6). Although the database does not record the level of affects to each PMU that falls within these nonnative categories, we know there is a strong correlation between the removal or suppression of nonnatives and the increase in population numbers of roundtail chub and other native fish species (Marks *et al.* 2009, p. 25).

Table 5-6: Ranking system for assessing nonnative communities that co-occur with roundtail chub.

Code	Qualitative Description
High	Nonnative community contains at least one high effect species.
Medium	Nonnative community contains at least one moderate effect species.
Low	Nonnative community contains at least one low effect species.
None	No nonnative species present.

Across the range, most of the PMUs either had a nonnative community in the High category (44%) or no nonnative community (36%). Two HUCs, Lower Gila-Agua Fria and Santa Cruz, had no occupied areas with any nonnative species in High.

Table 5-7. Number of PMUs occupied by the nonnative fish community categories.

HUC Watershed	High	Medium	Low	None
Bill Williams	11	0	4	14
Lower Gila-Agua Fria	0	0	3	5
Salt	16	4	1	6
San Pedro	6	0	3	7
Santa Cruz	0	0	1	11
Upper Gila	14	4	7	5
Verde	24	2	3	10
Total	**71**	**10**	**22**	**58**

Comparing this to the population stability rankings, a substantial proportion of the occupied range has stable or increasing populations with all life stages present (80% of PMUs) even though they rank among the most severe nonnative community (44% of PMUs). We compared the overlap between population stability and nonnative community (Table 5-8). Across the PMUs, 34% have a population considered increasing (Category 1) and the most severe nonnative category (High). Of those populations considered stable or increasing (Category 1), 39% have no nonnatives, 12% have a community in Low, 7% in Medium, and 43% in High.

Table 5-8: Number of PMUs grouped by population stability ranking and nonnative community.

Population stability categories	**Nonnative community category**				
	High	Moderate	Low	None	**Total**
1	55	9	15	50	129
2	2	0	1	0	3
3	2	0	1	0	3
4	8	0	3	4	15
NA	4	1	2	4	11
Total	71	10	22	58	161

6 FUTURE SCENARIOS AND FUTURE RESILIENCY

We evaluated the future conditions of the roundtail chub in the Lower Colorado River basin using a stochastic model to simulate future occupancy within each PMU by watershed given different assumptions about future environmental conditions.

6.1 Roundtail Chub Population Model

6.1.1 Conceptual Model

Given the future stressors to roundtail chub populations, we constructed a simple conceptual model to demonstrate key factors in population resiliency (Figure 6-1). The model allows us to consider future conditions of each PMU in terms of probability of persistence given the state of these factors. Ultimately, the resiliency of chub populations is determined by the presence of habitat conditions to support successful spawning and recruitment of young to adults and the survival of adults. The major influence and likely limiting factor in the future for chub habitat is the availability of water to support stream flows throughout the year to provide habitat conditions for the species. We used occupied stream length as a simple surrogate for stream flows and habitat conditions; we assumed longer streams provide more suitable habitat. We recognize that occupied stream length does not always correlate with improved habitat conditions and stream flow. However, we think stream length is closely related to habitat conditions and it provided a consistent metric we could apply to each PMU. We assumed that, if all other factors were equal, longer streams support more resilient chub populations than shorter streams because of increased habitat availability supporting larger chub populations (Stefferud *et al*. 2011, p. 12). The primary influence on occupied stream length is associated with the availability of streamflow resulting from overall climatic conditions over time.

Precipitation patterns are also critical for providing the large winter and spring floods that are important for supporting successful spawning and recruitment annually. If changing climate conditions result in more years without these beneficial floods, we expect that recruitment would decline and overall resiliency would decline and extirpation risk for chub populations would increase.

The other primary driver for roundtail chub population resilience relates to the presence of nonnative species in the streams where they exist. Nonnative species can influence adult survival and recruitment of young through competition with and predation on various life stages. As highly influential nonnative species increase, we expect roundtail chub recruitment and survival to decrease, as well as population resiliency. The primary drivers of the presence of nonnatives are their unintentional spread (via either natural range expansion or additional human releases) and the management efforts to reduce the spread and to actively remove them from places where roundtail chub populations currently occur.

The final factor considered in the model is the ability of roundtail chub to recolonize streams following extirpation events. The more hydrological connections a PMU has, without a stream barrier, to other occupied PMUs, the higher likelihood that roundtail chub would recolonize an extirpated PMU through natural dispersal. Management by fisheries managers can also influence recolonization through intentional stocking of roundtail chub into extirpated streams.

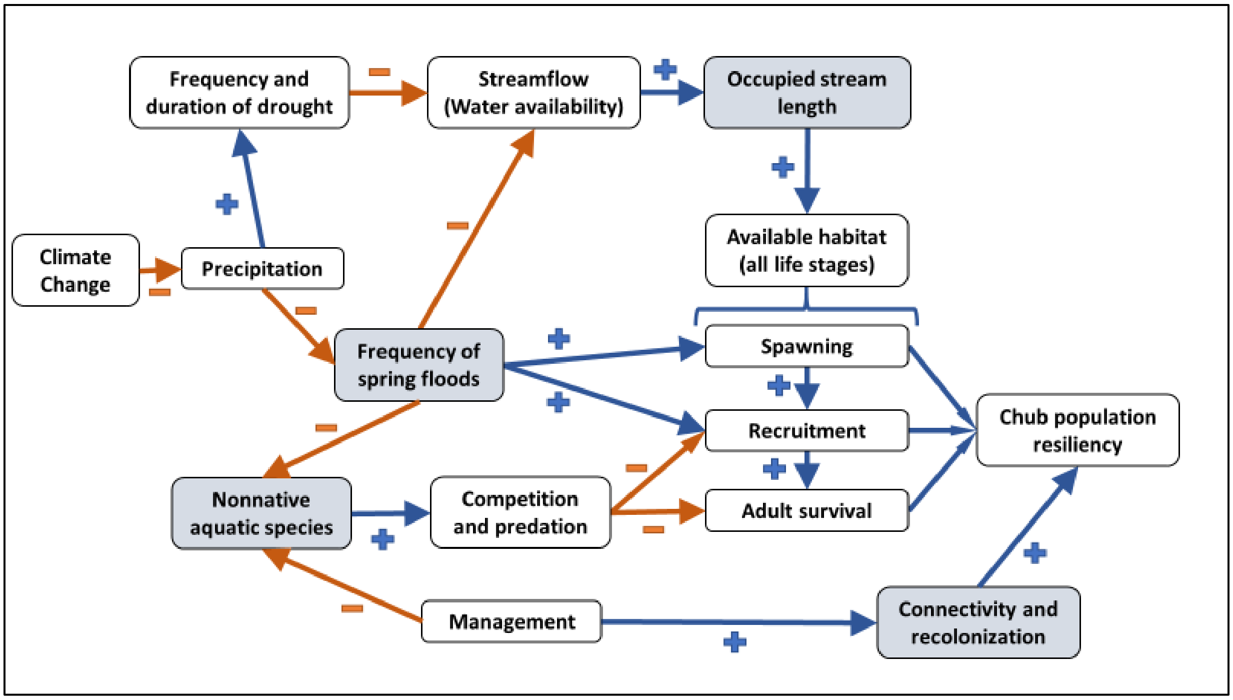

Figure 6-1: Conceptual ecological model for roundtail chub. Dark boxes indicate parameters in the occupancy model.

6.1.2 Occupancy model

The roundtail chub's range in the Lower Colorado River basin is comprised of many populations of varying size and connectivity. We have limited detailed information on the specific demographic status of the vast majority of the streams within which the species occurs. We can, however, assess the factors affecting roundtail chub resiliency through a risk analysis to estimate the probability of persistence of each PMU (see 5.4 Methodology for Assessing Extant Populations) given the current and future state of a few key variables. We used the occupied stream length for each PMU, the nonnative community, the probability of a beneficial flood and the number of connected occupied PMUs to construct a simulation model to estimate the future occupancy of the PMUs. The model was limited to the currently occupied PMUs and did not account for potential range expansion. This occupancy model can be run using different future scenarios of those key variables. For a more detailed description of the modeling effort for roundtail chub see Appendix F.

We parameterized the occupancy model using a combination of empirical data and expert elicited information. We used the Database to establish the current conditions of the PMUs in terms of the occupied stream length, presence of the nonnative community, and number of connected PMUs (see Appendix E for the current stream conditions). A few currently occupied streams were not in the Database (mainly streams on Tribal lands), and we collected available information on those streams to complete the starting conditions. We completed a separate evaluation to estimate the current probabilities of beneficial floods for each PMU (see Appendix F, *Flood effects*, for more information on that parameter).

We used an expert elicitation process to develop much of the model (see Appendices F and G). The elicitation resulted in a range of estimates in the risk of extirpation of a stream given no management and certain conditions of the stream (occupied stream length, presence of nonnative communities, and years since a beneficial flood). Since the elicitation was completed in 2016 (when we considered Gila and headwater chubs as separate species from roundtail chub), we have received new information documented in the Database that provided a more complete description of the current and historical condition of the roundtail chub. Using information from the Database, we estimated the number of stream segments that have been lost in recent years based on empirical data (see Appendix D for a list of extirpated streams). Based on the last 50 years of evidence showing a loss of about 2% of PMUs per decade (see Appendix F, *Ongoing management actions*, and Table F-6 for additional explanation), the expert elicitation resulted in estimates of risks that exceeded actual rates of extirpation that have been observed by more than order of magnitude. Therefore, for three of the four future scenario runs of the model (see below) we reduced the risk estimates by an order of magnitude to bring them closer into alignment with the recent empirical data. We also have updated summary information for conservation management efforts since 2004 that we have used to inform the model parameters related to transition of nonnatives and the probability of recolonization of extirpated streams from stocking (see conservation actions section for more detail and Appendix F, *Ongoing management actions*, for additional explanation). We recognize there are a number of limitations in this application of elicitation opinion, however given the substantial uncertainty regarding the risks posed to the species by various threats, we think it is a reasonable application of expert knowledge, once the scale of risks was adjusted to be more closely reflect recent base rates of extirpations.

To estimate the future resiliency of roundtail chub PMUs we ran the occupancy model under four different sets of assumptions relative to future environmental and management conditions. The intent of the scenarios is to account for the uncertainty associated with any projection of the future. For this assessment, we also used the first scenario to evaluate the differences in future status projections given the risks elicited from the experts under prior knowledge of the species and assuming no management effects.

6.1.3 Future Scenario Descriptions

We built the scenarios around the future assumptions related to conservation management and future climate change effects (Table 6-1). Management was either nonexistent (Scenario 1), similar to levels in recent decades (Scenarios 2 and 3), or enhanced (Scenario 4). Ongoing management efforts include reducing overall risks to species and nonnative spread (Scenarios 2-4), and increased potential for recolonization (beyond natural rates) from stocking (Scenario 4). High climate change effects were included in Scenarios 3 and 4 by reducing the average stream lengths for all PMUs by 10.5% in 30 years (and proportionally to 50 years) and reducing the probability of beneficial spring floods by 25% (see Appendix F for more details).

Table 6-1: Summary of assumptions for future scenarios in roundtail chub occupancy model. Scenario 1 used risk estimates as elicited and assessed from experts. Scenarios 2-4 used reduced risk values.

	SCENARIOS			
Factors	**1. No Mgt & Low Climate Change Effects**	**2. Ongoing Mgt & Low Climate Change Effects**	**3. Ongoing Mgt & High Climate Change Effects**	**4. Enhanced Mgt & High Climate Change Effects**
Management	No Management Efforts	Ongoing Management Efforts	Ongoing Management Efforts	Enhanced Management Efforts
Nonnatives	*Spread as assessed.*	*Reduced spread.*	*Reduced spread.*	*Reduced spread. Increased nonnative removals.*
Recolonization	*Recolonization as assessed.*	*Recolonization as assessed.*	*Recolonization as assessed.*	*Recolonization as assessed. Increased management stocking.*
Climate Change	No additional climate effects.	No additional climate effects.	Increased climate effects.	Increased climate effects.
Stream Length	*Stream length as assessed.*	*Stream length as assessed.*	*Decreased stream lengths.*	*Decreased stream lengths.*
Flood Frequency	*Beneficial flood frequency as assessed.*	*Beneficial flood frequency as assessed.*	*Decreased flood frequency.*	*Decreased flood frequency.*

Scenario 1 (**No Mgt & Low Climate Change Effects**) assumes no conservation management is in place and low climate change effects. We used all parameter values as elicited and assessed from the experts in 2016 (Appendix G), including the risks and the rates of future spread and loss of nonnatives (described in Appendix F). We elicited these risks under the assumption that no management would occur. This is not a traditional future scenario because it does not represent a variation of the future based on different assumptions of environmental changes, but instead Scenario 1 is an alternative hypothesis about the overall risks attributed to the species from the current conditions. The risks provided by the elicitation appear to be much higher than the empirical data observed over the last 50 years indicates (see above under Occupancy Model). Therefore, we presume this scenario is a substantial overestimate of potential effects of the stressors.

Scenario 2 (**Ongoing Mgt & Low Climate Change Effects**) assumes conservation management actions are ongoing in the future in a similar fashion to the efforts that have been occurring for at least the last 15 years. We also assume low climate change effects with no directional changes in stream lengths or beneficial spring flood frequencies. Based on the ongoing management assumptions, we reduced parameter values as elicited from the experts in 2016 by an order of magnitude to approximate the risks to stream extirpations observed over the past 50 years (as described above and in Appendix F). This reduced the risk assessments for all stressors and reduced the potential for nonnative species transitions getting worse by an order of magnitude compared to estimates we elicited. We also made these adjustments for Scenarios 3 and 4.

Scenario 3 (**Ongoing Mgt & High Climate Change Effects**) also assumes ongoing conservation management but higher climate change effects. To simulate climate effects, we assumed all of the stream lengths would decrease by 10.5% from their current lengths over the next 30 years and continuing at a similar rate of reduction through 50 years. We applied this reduction as a proportional annual decline (Appendix F). We also reduced the probability of an annual beneficial spring flood by 25% compared to the current probability to simulate potential effects of climate change that could reduce the frequency of beneficial floods during winter and spring. On average, this results in the chance of a spring flood each year declining from about 40% to 30% over the 50 years of the model run (Appendix F).

Scenario 4 (**Enhanced Mgt & High Climate Change Effects**) assumes enhanced conservation management and higher climate change effects. The enhanced conservation effort assumes that nonnative transitions improve because of increased nonnative removal efforts. To simulate these efforts, we increased the probabilities of nonnative community transitions to better categories by 50% over those in the ongoing management scenarios. In addition, to simulate increased efforts of restocking streams that become extirpated in the future, if the stream has a lower nonnative category (0, 1, or 2) we increased the recolonization probability to 40% every year. This simulates increased efforts for restocking and increases the number of recolonized streams. We did not simulate the potential for range expansion in the model, so the maximum number of PMUs potentially occupied was the currently occupied PMUs. The effects of climate change were simulated in the same way as in Scenario 3.

6.1.4 Timeframe

We chose to run the model for 50 years into the future. This timeframe likely represents about six to eight generations for roundtail chub (assuming generation time is the average age of reproducing adults, and that average adult ages are in the six to eight-year range). We have high uncertainty about the relationship between future climate change and the expected variation in the parameters of our model (specifically changes in stream length and flood frequency), as these are not confidently projected in climate models, and the future trends in precipitation in the southwest is particularly difficult to project due to uncertainty around modeling summer monsoonal rain (Fassnacht 2006, p. 2196). In addition, projecting ongoing management into the future beyond 50 years increases our uncertainty significantly.

6.2 Future Status

6.2.1 Model Results

The results of the occupancy model project the median and upper and lower bounds (95% confidence interval) for the number of persisting PMUs over time under each scenario (Figure 6-2, Table 6-2). Our model projected that the number of extant PMUs across the range are expected to decline in all scenarios, but the severity of decline was much greater for Scenario 1, which used the expert elicited values in the absence of management. Starting with 159 occupied PMUs (excluding two sites that are included in the current condition), under Scenario 1 there were a median of 62 PMUs remaining occupied at 30 years and 48 at 50 years (Table 6-2). The other three scenarios exhibited similar patterns of less severe decline with approximately 123 to 145 PMUs remaining occupied range-wide at 30 years and 113 to 142 PMUs occupied at 50 years (Table 6-2, Figure 6-2). Climate effects modeled in Scenarios 3 and 4 had minimal effect on future status. Enhanced conservation efforts of decreasing the spread of exotics and increasing restocking rates after stream extinctions, as simulated in Scenario 4, exhibited some capacity to counteract possible stressors on chub populations. We did not include in the model an opportunity for the expansion of PMUs occupied beyond the initial number. This effectively underestimates the potential for management effects and overestimates the potential total number of extirpations because management agencies have in recent past expanded the number of streams occupied by chubs through stocking (see 4.9 Conservation Actions above).

Table 6-2: Median number of PMUs occupied, 2.5 percentile (lower bound) and 97.5 percentile (upper bound) at 30 years and 50 years for all 4 scenarios. The initial number of streams, 159, excludes two sites that are included in the current condition.

	30 years			**50 years**		
	median	**lower bound**	**upper bound**	**median**	**lower bound**	**upper bound**
Scenario 1	62	50	73	48	34	64
Scenario 2	133	123	139	126	113	133
Scenario 3	133	125	141	125	116	134
Scenario 4	140	133	145	138	131	142

We also evaluated the number of PMUs projected to persist within each of the remaining seven HUC6 watershed analysis units. The number of streams projected as extant in each analysis unit varied among future conditions scenarios. Under Scenario 1 (using elicited values and assuming no management), all seven watersheds experienced a decline in occupied PMUs by >45% in the first 30 years (Table 6-3, Figure 6-3). The other scenarios exhibited only moderate declines with each watershed declining between 3-25% in the first 30 years of the simulation (Table 6-3, Figure 6-4). Sensitivity analysis of the models suggests that the most important aspects to roundtail chub persistence were related to the potential for streams to be invaded by additional nonnative species with severe effects and the ability for streams to be recolonized if extirpated (Appendix F). This recolonization can happen naturally through connected streams or through managed stocking.

We also calculated the total stream lengths within each HUC06 watershed that fell within different risk categories based on the probability of persistence estimate by the model for each PMU over the next 50 years (Table 6-4). We separated the risks into 0.2 bins, such that the highest probability of persistence was 0.8 to 1 and the lowest was 0 to 0.2 probability of persisting at 50 years under each of the four scenarios. The stream lengths in each bin are the total length of all the PMUs with that range of probabilities of persistence. Maps of these results showing the persistence categories by stream are depicted in maps of each watershed in Appendix H.

Table 6-3: Median number and proportion (%) of streams (PMUs) occupied (and the lower (LB) and upper bound (UB) of the 95% confidence interval) under each of the four future scenarios for each of the seven representation units (HUC06 watersheds).

			Scenario 1			**Scenario 2**			**Scenario 3**			**Scenario 4**		
	Watershed	**Initial**	**Median(%)**	**LB**	**UB**	**Median(%)**	**LB**	**UB**	**Median(%)**	**LB**	**UB**	**Median(%)**	**LB**	**UB**
Year 30	Bill Williams River	29	13(45)	7	19	26(90)	23	28	25(86)	22	28	26(90)	23	29
	Upper Gila River	29	10(35)	3	16	24(83)	20	27	24(83)	20	28	25(86)	22	28
	San Pedro-Wilcox	16	4(25)	0	7	13(81)	10	15	13(81)	10	15	13(81)	10	15
	Santa Cruz River	12	3(25)	0	6	11(92)	9	12	11(92)	9	12	12(100)	11	12
	Salt River	26	8(31)	2	14	19(73)	15	23	20(77)	16	23	21(81)	18	23
	Verde River	39	21(54)	17	26	33(85)	29	36	33(85)	29	36	34(87)	31	37
	Lower Gila-Agua Fria	8	3(38)	0	6	7(88)	6	8	7(88)	6	8	8(100)	7	8
Year 50	Bill Williams River	29	9(31)	0	17	25(86)	20	28	25(86)	22	28	26(90)	24	28
	Upper Gila River	29	8(28)	1	14	23(79)	18	27	23(79)	19	26	24(83)	21	28
	San Pedro-Wilcox	16	2(13)	0	6	12(75)	7	15	11(69)	8	14	13(81)	11	15
	Santa Cruz River	12	1(8)	0	3	10(83)	8	12	10(83)	8	12	12(100)	10	12
	Salt River	26	5(19)	0	10	18(69)	14	22	18(69)	14	22	20(77)	17	24
	Verde River	39	20(51)	16	25	31(79)	28	34	31(79)	27	35	34(87)	31	36
	Lower Gila-Agua Fria	8	3(38)	0	5	7(88)	5	8	7(88)	5	8	8(100)	6	8

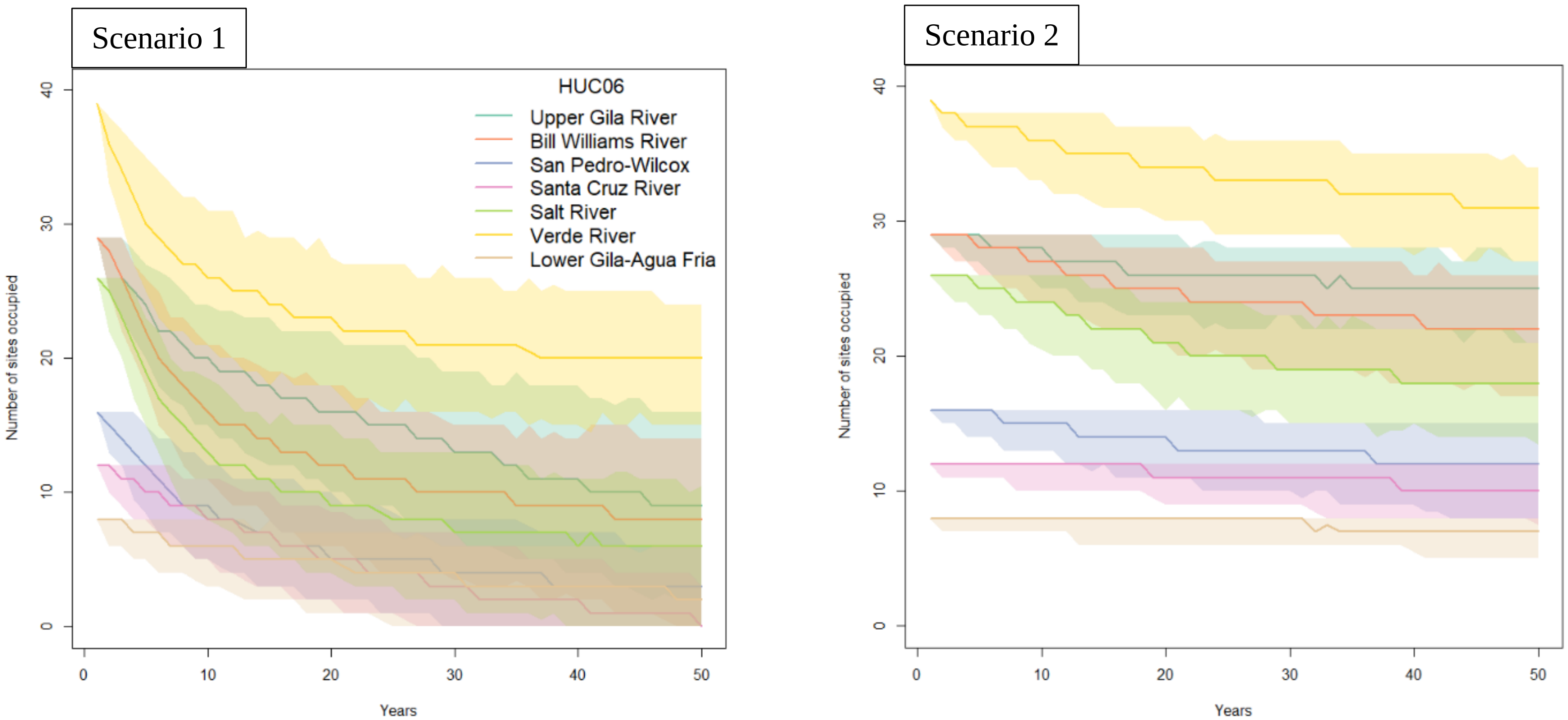

Figure 6-3: Median number of stream sites (PMUs) occupied under future conditions Scenarios 1 (left) and 2 (right), broken out by representation unit (HUC06 watershed designation) with 95% confidence intervals

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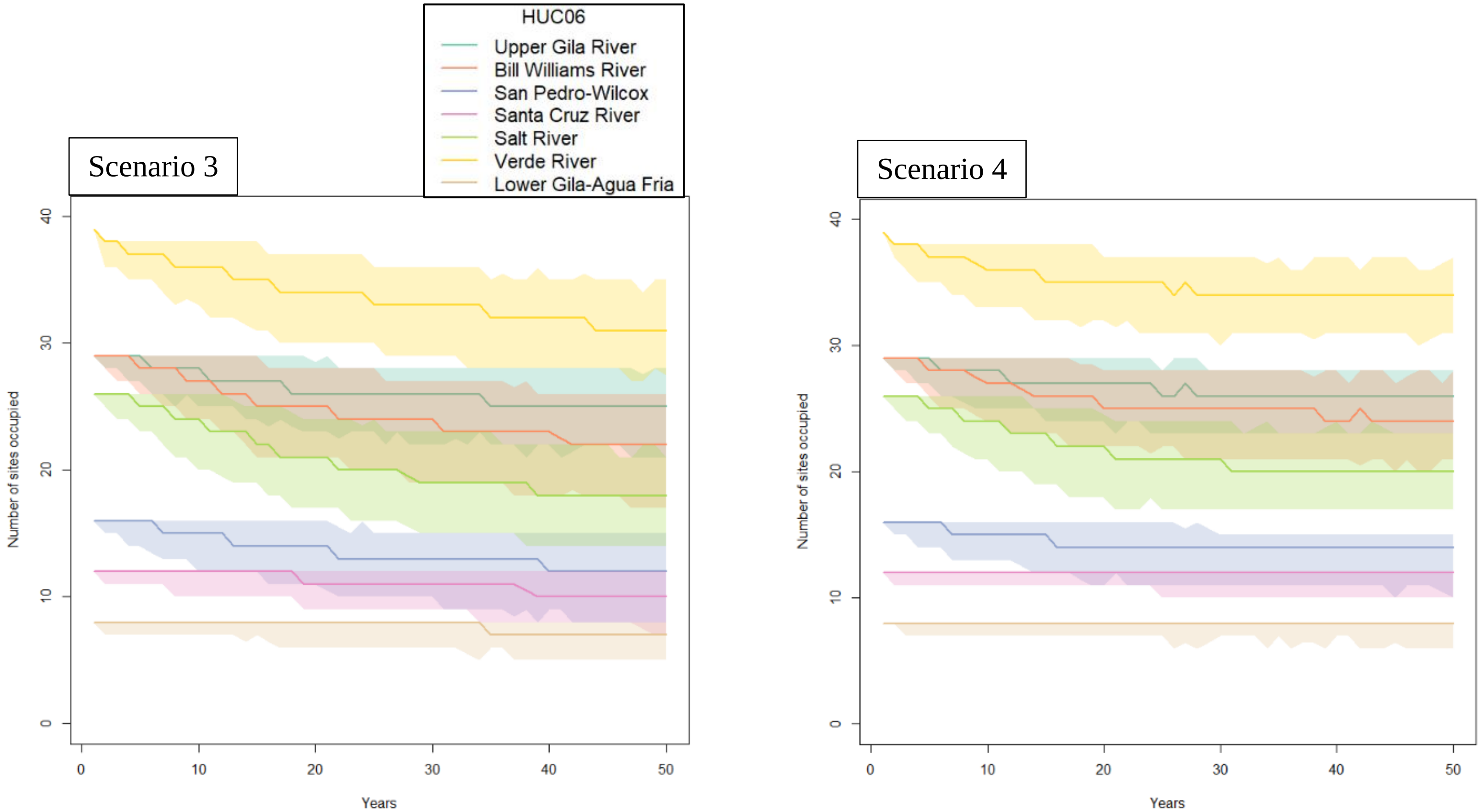


Figure 6-4: Median number of stream sites (PMUs) occupied under each of the 4 future conditions Scenarios 3 (left) and 4 (right), broken out by representation unit (HUC06 watershed designation) with 95% confidence intervals.

Table 6-4: Stream length (KM) and proportion (%) within each watershed of total stream length within each HUC06 watershed within five categories of probability of persistence projected in 50 years under four future scenarios.

Scenario 1 at 50 years	Stream KMs in Probability of Persistence Category					% of Stream KMs in Persistence Category				
Watershed HUC06	**0.8-1**	**0.6-0.8**	**0.4-0.6**	**0.2-0.4**	**0-0.2**	**0.8-1**	**0.6-0.8**	**0.4-0.6**	**0.2-0.4**	**0-0.2**
Bill Williams River			120.6	78.2	123.3			37%	24%	38%
Lower Gila-Aqua Fria			9.3	11.7	1.1			42%	53%	5%
Salt River			112.6	16.9	347.9			24%	4%	73%
San Pedro-Wilcox			14.0	1.0	50.9			21%	1%	77%
Santa Cruz River					24.1					100%
Upper Gila River			107.0	116.8	157.8			28%	31%	41%
Verde River	70.6	373.6			107.8	13%	68%			20%
Total Scenario 1	**70.6**	**373.6**	**363.5**	**224.5**	**812.8**	**4%**	**20%**	**20%**	**12%**	**44%**
Scenario 2 at 50 years										
Bill Williams River	274.4	45.1		0.9	1.8	85%	14%		0%	1%
Lower Gila-Aqua Fria	21.0	1.1				95%	5%			
Salt River	253.4	72.6		1.4	149.9	53%	15%		0%	31%
San Pedro-Wilcox	17.4	8.5	1.8	0.6	37.4	26%	13%	3%	1%	57%
Santa Cruz River	17.3	6.7		0.2		72%	28%		1%	
Upper Gila River	223.8	87.9	11.0		58.9	59%	23%	3%		15%
Verde River	461.3	6.1	35.8	4.0	44.8	84%	1%	6%	1%	8%
Total Scenario 2	**1268.6**	**228.0**	**48.6**	**7.1**	**292.9**	**69%**	**12%**	**3%**	**0%**	**16%**
Scenario 3 at 50 years										
Bill Williams River	241.8	77.6		0.9	1.8	75%	24%		0%	1%
Lower Gila-Aqua Fria	21.0	1.1				95%	5%			
Salt River	276.5	49.6	1.4		149.9	58%	10%	0%		31%
San Pedro-Wilcox	16.3	9.7	1.8	0.6	37.4	25%	15%	3%	1%	57%
Santa Cruz River	17.3	6.7		0.2		72%	28%		1%	
Upper Gila River	241.2	81.4			58.9	63%	21%			15%
Verde River	466.5	0.9	35.8	4.0	44.8	85%	0%	6%	1%	8%
Total Scenario 3	**1280.6**	**227.0**	**39.0**	**5.7**	**292.9**	**69%**	**12%**	**2%**	**0%**	**16%**
Scenario 4 at 50 years										
Bill Williams River	301.0	19.3			1.8	93%	6%			1%
Lower Gila-Aqua Fria	22.1					100%				
Salt River	275.0	53.6		123.3	25.4	58%	11%		26%	5%
San Pedro-Wilcox	19.8	8.6			37.4	30%	13%			57%
Santa Cruz River	24.1					100%				
Upper Gila River	267.1	55.6		58.9		70%	15%		15%	
Verde River	507.3				44.8	92%				8%
Total Scenario 4	**1416.4**	**137.1**		**182.2**	**109.4**	**77%**	**7%**	**0%**	**10%**	**6%**

6.2.2 Resiliency

Roundtail chub populations are most at risk from the effects of nonnative species and hydrological changes related to climate change. We evaluated the implications of these stressors through an explicit occupancy model to project the number of PMUs persisting given certain risks associated with these stressors. We also projected the total length of streams in different risk categories. The resiliency assessment of these populations varies considerably depending on the scenarios, specifically depending on the parameter estimates used to quantify the risks. Using the expert-elicited values (Scenario 1) suggests a sharp decline in the future number of occupied PMUs and a large portion of the stream lengths (44% overall) being in the highest risk categories, despite opportunities for recolonization. The high elicited extinction risks, primarily due to the effects of nonnatives and the elevated transition rates between nonnative communities, resulted in mainly PMUs persisting that currently have no nonnative communities. These results represent large declines and would suggest the species has low resiliency to the ongoing stressors.

However, as previously noted, these elicited values produced estimates of extinction risk that far exceed current rates of extirpations observed over the past several decades. By reducing the elicited values by an order of magnitude, we think Scenarios 2-4 better represent plausible projections based on comparisons to empirical data. Although some loss of PMUs and some elevated extirpation risks remain anticipated under all three of these scenarios, the projected modest declines are substantially less than under Scenario 1 and the model stabilizes at a point in which most PMUs continue to be occupied. The results from both ongoing management scenarios without and with additional effects of climate change (Scenarios 2 and 3) result in more moderate changes in the number of occupied PMUs and extirpation risks compared to the current condition. The current 159 PMUs are projected to decline to between 134 and 113 PMUs (16 and 29% decline) under those two scenarios over 50 years (Table 6-2) and about 69% of the current occupied stream lengths being in the highest persistence category (Table 6-4). Overall, these results suggest that existing roundtail chub populations are resilient to the stressors modeled under more empirically based parameters.

Many of these PMUs, despite their likelihood of persisting under Scenarios 2, 3, and 4, occupy relatively short stream lengths, particularly headwater portions of watersheds. Twenty-six PMUs occupy stream segments less than 1 km; 82 are less than 5 km. Scaling to the population-level, 19 of the populations (23% of total) occupy stream segments less than 1 km; 45 (55% of total) are less than 5 km. In our elicitation and modeling, the extirpation due to stochastic environmental events was incorporated by increasing the baseline probability of extirpation at smaller stream lengths. The model did not, however, incorporate potential genetic processes that may reduce resiliency of populations, such as inbreeding or low of genetic diversity. We do not have evidence that reductions in genetic diversity or inbreeding are affecting the fitness of individual roundtail chub or overall population viability. Also, even short stream reaches, if they support high densities, may contain sufficient effective sizes to reduce the potential for genetic drift to cause a loss of genetic diversity. Headwater populations have reduced genetic diversity, likely due to historical isolation, (Dowling *et al.* 2015, pp. 13-16), but have persisted for thousands of years despite having reduced gene pools and limited potential for gene flow. Thus, we think it is reasonable to assume at this point genetic processes are unlikely to be affecting the viability of roundtail chub populations.

At the same time, previously connected stream segments are now isolated due to barriers or manipulations of the hydrology of the watershed. In theory, isolation could lead to reductions in genetic diversity that may affect viability. Future monitoring efforts should investigate the effective size of remaining roundtail chub populations to determine whether they can support and retain of genetic diversity and minimize the potential for inbreeding.

6.2.3 Redundancy

The distribution of the roundtail chub within the Lower Colorado River basin has experienced substantial reduction from the estimated historical condition, losing approximately 66% of its occupied stream miles (Figure 5-1, Table 5-1). The historical losses are most pronounced in the larger mainstem rivers of the Gila River drainage where the species no longer occurs. This reflects a reduction in the redundancy for the species and its ability to withstand wide-scale catastrophic events (such as a severe drought). However, the species continues to occur in at least 159 PMUs within 83 populations across seven watersheds in Arizona and New Mexico, providing substantial population numbers and distribution.

Using the occupancy model, we projected the potential changes in the number of occupied PMUs and proportions of the stream lengths at extirpation risk over the next 50 years within the seven remaining watersheds given stressors related to nonnative species and climate change. While all seven watersheds are expected to experience some reductions in the number of occupied PMUs, none of the watersheds are anticipated to become unoccupied. The Lower Gila-Agua Fria and Santa Cruz River watersheds currently have the smallest occupied number and lengths of stream. Under Scenario 3 with ongoing management and high climate effects, the Lower Gila-Agua Fria watershed is projected to have five to eight PMUs remaining with 95% of the stream lengths in the highest persistence category, and the Santa Cruz River watershed is projected to have eight to 12 PMUs remaining with 72% of the stream lengths in the highest persistence category (Tables 6-3, 6-4).

It is also important to note that none of the scenarios account for roundtail chub occupying new PMUs due to management efforts of stocking additional streams not currently occupied. Our input data only considered PMUs currently occupied by roundtail chub, but management agencies have stocked and reestablished them into areas previously unoccupied (Appendix B). Additional successful stockings in the future would contribute additional redundancy.

6.2.4 Representation

Given the documented genetic diversity across this portion of the species' range, conserving as much of that diversity as possible is important for maintaining future adaptive capacity. Most of the estimated historical distribution, which includes most large river portions, no longer supports roundtail chub and they have been extirpated from entire HUC06 watersheds (Figure 5-1, Table 5-1). It is unknown whether many of these streams supported self-sustaining roundtail chub populations or merely served as conduits for movement. Therefore, it unknown what has been lost with the extirpation of roundtail chub from these areas, such as unique genetic diversity, life history types, or ecological conditions that are no longer captured by extant populations.

However, as described in the Redundancy section above, we projected low to moderate declines in all currently occupied HUC06 watersheds under Scenarios 2-4. These HUC06 watersheds cover an array of ecoregions and are subjected to different environmental conditions (Appendix C), along with supporting genetically distinct groups that likely possess differing levels of adaptive variation (Dowling *et al*. 2015, entire; Copus *et al*. 2018, entire). While some declines are notable, we do not expect chub to become extirpated within any of the s, or close to extirpated, over the next 50 years. Therefore, we expect that roundtail chub would experience limited loss of current representation resulting from the projection of future status.

We used the HUC06 watersheds as analysis units to consider the ecological and genetic diversity within the roundtail chub from the Lower Colorado River basin. Although genetic diversity can be broadly partitioned at these scales, there is also considerable diversity within these watersheds (Dowling *et al.* 2015, pp. 13-16). Thus, populations within an individual HUC06 watershed should not be considered redundant in terms of the genetic diversity they contribute to the overall species in the Lower Colorado River basin. Managers have implemented practices to source restocking efforts using the same original genetic stock or one from the nearest and most similar location when possible.

6.2.5 Summary

Based upon our assessment of the current and future condition of roundtail chub in the Lower Colorado River basin, we think that the following three factors will continue to influence the trajectory of roundtail chub into the future: natural flows, high effect nonnative species, and management. A natural flow regime maintains water quality and quantity (meaning perennial flows), as well as the seasonal high flow events that support roundtail chub recruitment and population connectivity. Substantial modifications to the natural flow regime, such as prolonged periods of drought (*i.e*., reduction in flow) or years between seasonal high flow events could affect recruitment. The future condition of watersheds within the Lower Colorado River basin is uncertain based on climate change predictions that indicate, in general, aquatic habitats will decrease and human demand for water resources will increase. However, the results of our assessment suggest that the projected levels of future changes in hydrologic conditions on the order of a 10% reduction over 30 years has only minimal effects on overall persistence probabilities.

Nonnative species can pose a substantial threat to roundtail chub, depending on which nonnative species and the site-specific habitat conditions of different streams. As the current condition shows, roundtail chub can persist in streams despite the presence of one or more nonnative species. However, modifications to natural flow regimes likely exacerbate the effects of high impact nonnative predators (*e.g*., green sunfish, smallmouth bass). These effects would be further compounded on smaller populations, due to decreases in habitat availability that increase exposure of chub, particularly younger age classes, to nonnative predators.

Management is critically important to roundtail chub persistence because a focus on protection of existing populations has benefitted roundtail chub based upon our assessment of the current condition and our future scenarios. The 3 Species Conservation Plan, as well as watershed and land management efforts by agency, tribal, and non-governmental organizations, is ensuring that roundtail chub continue to persist, and even thrive in some cases, in multiple populations across the remaining seven watersheds. The roundtail chub, due to the importance of natural flow and the need to control nonnatives, is likely dependent upon conservation management to continue to improve upon the species current condition in the Lower Colorado River basin. Our assessment indicates that currently management efforts are effective and are incrementally improving the status of roundtail chub.

APPENDIX A: ROUNDTAIL CHUB RESOURCE NEEDS BY LIFE STAGE

Life Stage: Spawning to Eggs

Resource	**Resource Needs**	**Citation**
Temperature	Range of 12-22˚C (54-72˚F) in White River, Verde River, and lab	Brouder et al. 2000, p. 13; Carlson et al. 1979, p. 72-73
Temperature	18.3°C (64.9°F) in Upper Verde River	Brouder et al. 2006, p. 262
Temperature	In Fossil Creek spawning temperature varied from 19-23°C (66-73°F)	Neve 1976, p. 4
Temperature	Spawning occurred (in the lab) at temperatures ranging from about 15-26°C (59-79°F); however, chub spawned less frequently at temperatures above 24°C (75°F)	Schultz and Bonar 2016, p. 280
Temperature	In Bonita Creek, spawning behavior observed at water temperature of 21.7°C (71°F)	Schultz and Bonar 2006, p.31
Temperature	In Turkey Creek, New Mexico, expressed gametes upon handling at water temperatures of 22°C (72°F)	Bestgen 1985, p. 64
Spawning Cues	After peak spring flows when flows are declining	Brouder 2001, p. 306; Bestgen et al. 2011, p. 13 and many other authors
Spawning Cues	Correlated with peak annual discharge, higher discharges provided more recruitment	Muth and Nesler 1993, p. 22
Spawning Cues	Spawned 3 weeks after a spring “spate”	Brouder et al. 2000, p. 13
Spawning Cues	Author hypothesized that temperature was the most significant environmental factor triggering spawning because it affects many physiological processes of poikilothermic animals and may include hormonal and physical activity controls. This parameter seemed to be the only consistent cue that fish could respond to during the two reproductive seasons studied.	Bestgen 1985, p. 64

Resource	Resource Needs	Citation
Habitat	Eggs are adhesive and stick to rocks, are broadcast near shore	Baxter and Simon 1970, p. 69
Habitat	Depending on water temperature, eggs usually hatch within four to 15 days after spawning.	Rees et al. 2005, p. 13
Habitat	Adhesive eggs were laid over clean gravel (which comprised 78% of the overall substrate) in water with a mean depth of 31.6 cm (12.5 in)	Brouder et al. 2006, p. 261
Habitat	Pools with clean gravels and runs with silt/sand and gravel with no cover, flows are low	Minckley 1981, p. 187, 191
Habitat	Egg development occurs in substrate	Neve 1976, p. 14
Habitat	Pool-riffle areas with sandy/rocky substrates	Neve 1976, p. 14
Habitat	In Bonita Creek, researchers observed spawning behavior in a swift-moderate flowing section of a larger run with mixed substrate of mostly cobble, pebble, gravel, and fines, with low cover.	Schultz and Bonar 2006, p.31

Life Stage: Larvae/Young of Year

Resource	Resource Needs	Citation
Temperature	Eggs hatched in about 7 days at 18˚C (64˚F)	Bestgen and Zelasko 2004, p. 1
Temperature	Most growth and least mortality in lab study was at 27°C (81°F)	Bonar et al. 2011, p. 22
Temperature	Least growth and average mortality at 19.5°C (67°F)	Bonar et al. 2011, p. 23
Temperature	Mortality was highest at 30°C (86°F)	Bonar et al. 2011, p. 24
Temperature	In the lab, optimal temperature for larval chub growth was 28ºC (82°F), while optimal temperature for their survival was 24ºC (75°F)	Bonar et al. 2011, p. 97
Habitat	Low to no velocity areas associated with backwaters, pools, and runs, ephemeral shoreline habitats, vegetated shorelines. Use a variety of substrates	Bonar and Mercado Silva 2013, p. 24; Muth and Nesler 1993, p. 20; Ruppert et al. 1993, p. 397; Brouder et al. 2000, pp 6-7

Resource	Resource Needs	Citation
Habitat	Swifter, shallower water than adults	Ecology Audits 1979, p. 30
Habitat	Pools and areas with undercut banks and slow currents	Anderson 1978, p. 19
Habitat	Used areas along streambanks and shallow backwaters	Neve 1976, pp. 5, 14
Habitat	Ate diatoms and filamentous algae all year	Neve 1976, p. 14
Habitat	Small (20-49 mm [0.8-2 in] TL) juveniles in Bonita Creek used cascades and runs. All size classes of chub in Cienega Creek strongly preferred pools. Small juvenile chub in Bonita Creek moderately preferred habitats with the highest level of woody cover and moderately avoided habitats with the lowest amount of cover.	Schultz and Bonar 2006, pp. 21-22
Depth	Used shallowest depths (≤20 cm and 21-50 cm [≤7.8, 8.2-19.6 in]) Avoided 50-100cm (19.6-39.3 in) and never found over 100 cm (40 in)	Brouder et al 2000, p. 7
Depth	Middle and bottom of water column, mean depth 14.9 cm (7 in)	Bryan et al. 2000, pp. 21, 61

Life Stage: Juveniles (< 100 mm Total Length (TL))

Resource	**Resource Needs**	**Citation**
Temperature	Maximum temperature tolerance ~37°C (~99°F) initial loss of equilibrium	Carveth et al. 2006, p. 1435
Temperature	Best growth at 20 and 24°C (68 and 75°F) in lab tests with artificial food	Bonar et al. 2011, p. 26
Depth	20-200 cm (7.8-78.7 in)	Bonar and Mercado Silva 2013, p. 24
Depth	Shallower portions of pools; 100% probability of use for depths over 18.3 cm (7.2 in) and no use of 2.4 cm (0.96 in)	Turner and Tafanelli 1983, p. 24-25
Depth	High selection for 0.9-1.5 m (3.0-4.9 ft) and low for greater than 2.1 m (6.9 ft)	Barrett and Maughn 1995, p. 302
Depth	Preferred 1-1.5 m (3-5 ft), but not greater than 2.1 m (7 ft)	Barrett 1992, p. 52
Depth	Mean depth 0.55 m (1.8 ft)	Paroz et al. 2006, p. 51
Depth	In Bonita Creek, all size classes of chub used habitats with moderate mean depths (25-75 cm [9-30 in]). In Cienega Creek, mean density of all size classes of chub in habitats with a mean depth of 50-75 cm [20-30 in] was at least twice that of most other depths.	Schultz and Bonar 2006, pp. 26-27
Flow	0.0-96 cm/s (0.0-3 f/s)	Bonar and Mercado Silva 2013, p. 24
Flow	Probability of use 100% at 0.09 m/s (0.3 f/s), 25% at 0.2 m/s (0.7 f/s) and 0% at 0.8 m/s (2.5 f/s)	Turner and Tafanelli 1983a, p. 25
Flow	Used low velocities	Brouder et al. 2000, p.7
Flow	Velocities near 1.6 m/s (0.5 f/s) preferred; those above 6.6 m/s (2.0 f/s) are not preferred	Barrett 1992, p. 49; Barrett and Maughn 1995, p. 302
Flow	Selected about 0.15 m/s (0.5 f/s) and avoided greater than 0.61 m/s (2 f/s)	Barrett and Maughn 1995, p. 305

Resource	**Resource Needs**	**Citation**
Flow	In Bonita Creek, juvenile size classes of chub were variable in selection of habitats with respect to flow velocity. In Cienega Creek, frequency of occurrence and habitat preference of chub of all size classes was highly skewed toward habitats with no discernable flow.	Schultz and Bonar 2006, p. 28
Food	In chubs <100 mm (<4 in) TL in the mainstem Gila River in New Mexico, algae is the predominant dietary component with trichopterans and miscellaneous insect parts comprising the majority of additional food items	Bestgen 1985, p. 46
Food	For feeding, young fish move from slow areas into shallower, faster areas at heads of pools	Bestgen 1985, p. 44
Food	Diet dominated by algae, caddisflies, and other insects, mostly small in size	Bestgen 1985, p. 48
Cover	Woody debris or other types	Bonar and Mercado Silva 2013, p. 24
Cover	All types of cover used	Barrett 1992, p. 52; Barrett and Maughn 1995, p. 302

Resource	**Resource Needs**	**Citation**
Cover	Small and large juvenile chub in Bonita Creek showed avoidance for areas with low cover and a strong preference for areas with high cover (75-100%). All size classes of chub in Cienega Creek showed a strong preference for habitats with 25-50% cover. Small juvenile chub in Bonita Creek moderately preferred habitats with the highest level of woody cover and moderately avoided habitats with the lowest amount of cover. Mean density of small juvenile, juvenile, and adult Gila chub in Cienega Creek did not differ with respect to woody cover. In Bonita Creek, small juveniles avoided habitats with low vegetative cover and large juvenile preferred habitats with the highest proportion (45% +) of vegetative cover. There was no evidence of a difference in mean density of small juveniles in Cienega Creek with respect to vegetative cover. All size classes of chub in Bonita Creek strongly preferred habitats with the lowest proportion (0-10%) of rock/boulder and algal cover and mostly avoided habitats with higher levels of rock/boulder cover.	Schultz and Bonar 2006, pp. 23-24
Habitat	Pools and riffles	Bonar and Mercado Silva 2013, p.24
Habitat	Large, deep pools are used for refuges during low flow conditions	Bower et al. 2008, p. 353
Habitat	Pools selected over riffles even when riffles were more abundant	Turner and Tafanelli 1983, pp. 6, 33-34
Habitat	Riffles used in the Bill Williams River	Kepner 1979, p. 15
Habitat	Pools and backwaters	Bestgen et al. 2011, p. 13
Habitat	Riffle/pool and submerged vegetation types less than 1m (3 ft) deep.	Ziebell and Roy 1989, p. 22
Habitat	Vegetated shorelines in glides (runs) in West Clear Creek (where there are smallmouth bass in the pools), pools in the upper Verde	Brouder et al. 2000, pp. 6-7
Habitat	Pools and areas with undercut banks and slow current	Anderson 1978, p. 19
Habitat	Shallower, low-velocity waters adjacent to overhead bank cover	Bestgen and Propst 1989, p. 407

Resource	Resource Needs	Citation
Habitat	Smaller substrate size, sand substrates particularly selected, little for large boulders or bedrock	Paroz et al. 2006, p. 51; Barrett 1992, p. 52; Barrett and Maughn 1995, p. 302
Habitat	Small (20-49 mm [0.8-2 in] TL) and large (50-79 mm [2-3 in] TL) juveniles in Bonita Creek preferred cascades and runs. All size classes of chub in Cienega Creek strongly preferred pools. In Bonita Creek, small juvenile chub preferred habitats dominated by organic substrate, whereas larger juveniles preferred habitats dominated by coarser substrate. Chub in Cienega Creek appeared to avoid habitats with mixed substrates.	Schultz and Bonar 2006, p. 22

Life Stage: Adults (>100 mm TL)

Resource	Resource Needs	Citation
Depth	Selected depths 2.1 m (6.9 ft) with few shallower or deeper	Barrett and Maughn 1995, p. 301
Depth	20-200 cm (8-79 in)	Bonar and Mercado Silva 2013, p. 24
Depth	Chub used 21-50 cm (8 -20 in) pools 38.6% of time and 51-100 cm (20-39 in) pools 35.7% of time. Avoided areas ≤ 20 cm (8 in)	Brouder et al. 2000, p. 7
Depth	Deep (>1.8 m [6 ft]), but occasionally used shallower (<0.9 m [3ft])	Barrett 1992, p. 48; Barrett and Maughn 1995, p. 302
Depth	In Bonita Creek, all size classes of chub preferred habitats with moderate mean depths (25-75 cm [10-30 in]). In Cienega Creek, mean density of all size classes of chub in habitats with a mean depth of 50-75 cm (20-30 in) was at least twice that of most other depths.	Schultz and Bonar 2006, pp. 26-27
Flow	Did not use velocities above 0.14 m/s (3.28 f/s)	Barrett and Maughn 1995, p. 301
Flow	When instream cover absent, used 0.23-0.76 m/s (0.75-2.5 f/s);	Turner and Tafanelli 1983, p. 30-31
Flow	15-25 centimeters per second (cm/s (0.5-0.7 f/s))	Rinne 1992, p. 39

Resource	**Resource Needs**	**Citation**
Flow	Selected ≤ 20 cm/s (0.65 f/s), used > 20 cm/s (0.65 f/s) in proportion to availability	Brouder et al. 2000, p. 7
Flow	Slow-flowing pools (< 0.009 m/s [0.33 f/s]) but did occasionally use swifter (> 0.044 m/s [1.5 f/s]) waters including riffles	Barrett 1992, p. 48; Barrett and Maughn 1995, p. 302
Flow	In Bonita Creek, adult chub avoided habitats with no flow velocity but used all other mean flow velocity categories roughly in proportion to their availability. In Cienega Creek, frequency of occurrence and habitat preference of chub of all size classes was highly skewed toward habitats with no discernable flow.	Schultz and Bonar 2006, pp. 28-29
Habitat	Concentrate in suitable pools	Kepner 1979, p. 15
Habitat	Use largest, deepest, and most permanent pools. Not all pools are selected	Minckley 1973, p. 166
Habitat	Pools about 2 m deep (6.5 ft) below riffles	Ziebell and Roy 1989, p. 22
Habitat	60% pools, 18% glides, and 10% runs	Rinne and Stefferud 1998, p. 19
Habitat	Pools, glides, low gradient riffles	Bryan et al. 2000, p. 19-20
Habitat	Found mainly in pool habitat, but also in riffle-run and run habitats	Paroz et al. 2009, p. 23
Habitat	Various substrates (fine sand to boulders with sand/gravel preferred)	Bestgen 1985, p. 41

Resource	Resource Needs	Citation
Habitat	In Bonita Creek, adult chub (80+ mm TL) preferred chutes and did not exhibit preference for other habitat types, and did not prefer any habitats based on cover. All size classes of chub in Cienega Creek strongly preferred pools. All size classes of chub in Cienega Creek showed a strong preference for habitats with 25-50% cover. Mean density of small juvenile, juvenile, and adult chub in Cienega Creek did not differ with respect to woody cover. Mean density of all size classes of chub in Bonita Creek did not differ with respect to woody cover. In Bonita Creek, adult chub preferred habitats with the highest proportion (45% +) of vegetative cover. There was no evidence of a difference in mean density of adult chub in Cienega Creek with respect to vegetative cover. Mean density of adult chub in Cienega Creek and Bonita Creek did not differ with respect to rock/boulder cover. All size classes of chub in Bonita Creek strongly preferred habitats with the lowest proportion (0-10%) of rock/boulder and algal cover and mostly avoided habitats with higher levels of rock/boulder cover. In Bonita Creek, adult chub preferred habitats dominated by organic substrate. Chub in Cienega Creek appeared to avoid habitats with mixed substrates.	Schultz and Bonar 2006, p. 23-24, 37
Food	Aquatic and terrestrial insects, fish, detritus dominate diet	Quist et al. 2006, p. 25
Food	Fish and other vertebrates added to diet of aquatic and terrestrial invertebrates, plankton, detritus and algae	Bestgen and Zelasko 2004, p. 21
Food	Top carnivore of native fish in its streams, preys on larvae and juveniles of other fishes	Rinne 1992, p. 40
Food	Feed in medium velocity runs (0.3-0.5 m/s [10-18 f/s]) away from streambanks; feed on surface, water column, and bottom	Bestgen 1985, pp. 44, 52

Resource	Resource Needs	Citation
Food	Opportunistic omnivores, varied seasonally; diet primarily of ostracods, larval insects, and plants, but at over 170 mm (6.7 in) size added fish and crayfish; algae, hellgrammites, crayfish, Dipteran larvae, may eat fish	Neve 1986, p. 10; Bestgen 1985, pp. 48, 52

References Cited

All references are listed in the Literature Cited Appendix I for the Roundtail Chub SSA report.

APPENDIX B: ROUNDTAIL CHUB CONSERVATION ACTIONS

Table B-1. The total number of stockings, augmentations (A), new introductions (I), reintroductions (R), range expansions (RE), active nonnative removal efforts, and completed removal efforts for roundtail chub in the lower Colorado River basin from 2004 to 2020. Specific locations on private land are not available. In those instances, we only provide a stream name.

HUC	Stream Name	Year/s	Number of introductions, reintroductions, and range expansions	Number of augmentations	Number of nonnative removal efforts conducted	Number of nonnative removals completed
Bill Williams River Watershed	Bill Williams River	2013	1 (RE)	0	0	0
Bill Williams River Watershed	Bill Williams River (Private Land)	2013	1 (I)	0	1	0
		2014	0	0	1	0
		2015	0	0	1	1
		2017	1 (I)	1 (A)	1	0
		2018	2 (RE)	2 (A)	2	0
		2019	0	0	2	0
		2020	0	2 (A)	2	1
Lower Gila-Agua Fria River Watershed	Hassayampa River (Private Land)	2012	1 (I)	0	0	0
		2013	0	1 (A)	0	0
Lower Gila-Agua Fria River Watershed	Lower Gila River Pond	2008	1 (I)	0	0	0
Lower Gila-Agua Fria River Watershed	Indian Creek	2019	0	0	1	0
		2020	0	0	1	0
Salt River Watershed	Ash Creek	2007	1 (I)	0	0	0
		2008	0	1	0	0
		2011	0	1	0	0
Salt River Watershed	Willow Springs Lake	2012	0	0	1	0
		2013	0	0	1	0
		2014	0	0	1	0
		2015	0	0	1	0
		2016	0	0	1	0

HUC	Stream Name	Year/s	Number of introductions, reintroductions, and range expansions	Number of augmentations	Number of nonnative removal efforts conducted	Number of nonnative removals completed
		2017	0	0	1	0
		2018	0	0	1	0
		2019	0	0	1	0
		2020	0	0	1	0
San Pedro River Watershed	Redfield Canyon	2007	0	0	1	0
		2008	0	0	1	0
		2009	0	0	1	0
		2010	0	0	1	0
		2011	0	0	1	0
		2012	0	0	1	0
		2013	0	0	1	0
		2014	0	0	1	0
		2015	0	0	1	0
		2016	0	0	1	0
		2017	0	0	1	0
		2018	0	0	1	0
		2019	0	0	1	0
		2020	0	0	1	0
San Pedro River Watershed	San Pedro River (Private Land)	2010	1	0	0	0
		2011	0	1 (A)	0	0
Santa Cruz River Watershed	Bear Canyon	2005	1 (I)	0	0	0
Santa Cruz River Watershed	Romero Canyon	2005	1 (I)	0	0	0
		2019	1 (RE)	0	0	0
Santa Cruz River Watershed	Sabino Creek	2019	1 (I)	0	0	0
Santa Cruz River Watershed	Santa Cruz River (Private Land)	2009	1 (I)	0	0	0
		2016	1 (I)	0	0	0
		2017	1 (I)	1 (A)	0	0
		2020	2 (I)	2 (A)	0	0

HUC	Stream Name	Year/s	Number of introductions, reintroductions, and range expansions	Number of augmentations	Number of nonnative removal efforts conducted	Number of nonnative removals completed
Santa Cruz River Watershed	Sweetwater Dam	2020	0	0	1	1
Upper Gila River Watershed	Blue River	2009	0	0	1	0
		2012	1 (I)	0	1	0
		2013	0	0	1	0
		2014	0	0	1	0
		2015	0	1 (A)	1	0
		2016	1 (RE)	0	1	0
		2017	0	0	1	0
		2018	0	0	1	0
		2019	0	1 (A)	1	0
Upper Gila River Watershed	Blue River (Bobcat Flat)	2020	1 (RE)	0	0	0
Upper Gila River Watershed	Bonita Creek	2008	0	0	1	1
		2016	0	0	1	0
		2017	0	0	1	0
Upper Gila River Watershed	Harden Cienega Creek	2015	1 (RE)	0	0	0
		2019	0	1 (A)	0	0
		2020	0	0	1	0
Upper Gila River Watershed	Mule Creek	2012	1 (I)	0	0	0
		2013	0	1 (A)	0	0
		2014	0	1 (A)	0	0
Upper Gila River Watershed	West Fork Gila River	2006	0	0	1	0
		2007	0	0	1	0
		2008	0	0	1	0
		2009	0	0	1	0
		2010	0	0	1	0
		2011	0	0	1	0
		2012	0	0	1	0
		2013	0	0	1	0
		2014	0	0	1	0
		2015	0	0	1	0
		2016	0	0	1	0
		2017	0	0	1	0

HUC	Stream Name	Year/s	Number of introductions, reintroductions, and range expansions	Number of augmentations	Number of nonnative removal efforts conducted	Number of nonnative removals completed
		2018	0	0	1	0
		2019	0	0	1	0
		2020	0	0	1	0
Verde River Watershed	Fossil Creek	2004	1 (R)	0	1	0
		2005	0	0	1	1
		2012	0	0	1	1
Verde River Watershed	Gap Creek	2012	1 (I)	0	0	0
		2014	0	1 (A)	0	0
		2015	0	1 (A)	0	0
Verde River Watershed	Oak Creek	2016	0	1 (A)	0	0
		2017	0	1 (A)	0	0
		2018	0	1 (A)	0	0
		2019	0	1 (A)	0	0
		2020	0	1 (A)	0	0
Verde River Watershed	Rarick Canyon	2018	0	0	1	0
		2019	1 (I)	0	1	1
		2020	1 (RE)	1 (A)	0	0
Verde River Watershed	Red Tank Draw	2016	0	0	1	0
		2017	0	0	1	0
		2018	0	0	1	0
		2019	0	0	1	0
		2020	0	0	1	0
Verde River Watershed	Roundtree Canyon	2008	1 (I)	0	0	0
		2009	0	1 (A)	0	0
		2012	0	1 (A)	0	0
		2013	0	1 (A)	0	0
		2014	0	1 (A)	0	0
Verde River Watershed	Spring Creek	2014	0	0	1	0
		2015	0	0	1	0
		2016	0	0	1	0
		2017	0	0	1	0
		2018	0	0	1	1
Verde River Watershed	Verde River	2015	0	1 (A)	0	0
		2016	0	1 (A)	0	0
		2018	0	1 (A)	0	0
		2020	0	1 (A)	0	0

HUC	Stream Name	Year/s	Number of introductions, reintroductions, and range expansions	Number of augmentations	Number of nonnative removal efforts conducted	Number of nonnative removals completed
Verde River Watershed	Verde River (Private Land)	2008	1 (I)	0	1	1
		2009	2 (I)	1 (A)	0	0
		2010	1 (I)	1 (A)	0	0
		2011	0	1 (A)	0	0
		2012	0	1 (A)	0	0
		2013	1 (I)	1 (A)	1	1
		2015	1 (I)	0	0	0
		2018	1 (I)	0	1	0
Verde River Watershed	Webber Creek	2018	1 (R)	0	0	0
		2019	0	1 (A)	0	0

APPENDIX C: DEFINING THE GEOGRAPHIC EXTENT OF THE LOWER COLORADO RIVER ROUNDTAIL CHUB SEGMENT

C-1 Background

The roundtail chub has a large range that spans much of the Colorado River basin. This range is not continuous, however, and there are major gaps in the basin, particularly in the mainstem Colorado River, where the species does not occur or does so at extremely low densities. For this reason, management of roundtail chub occurs around major watersheds within which the species has a more continuous distribution.

At the broadest scale, the most common demarcation used to divide the range of roundtail chub is into a lower and upper Colorado River basin portion (hereafter Lower Basin and Upper Basin). This demarcation has been used for a variety of reasons. First, there is a legal definition of the

Figure C-1. Map of Upper and Lower Basins of the Colorado River.
Credit: Bureau of Reclamation.

Lower and Upper Basins based on the Colorado River Compact. The division point is Lees Ferry, a point in the mainstem of the Colorado River about 30 river miles south of the Utah-Arizona boundary, just downstream of Glen Canyon Dam (Figure C-1).

The Upper Basin includes those parts of the states of Arizona, Colorado, New Mexico, Utah, and Wyoming within and from which waters naturally drain into the Colorado River system above Lees Ferry, and all parts of these States that are not part of the river's drainage system but may benefit from water diverted from the system above Lees Ferry.

The Lower Basin includes those parts of the states of Arizona, California, Nevada, New Mexico, and Utah within and from which waters naturally drain into the Colorado River system below Lees Ferry, and all parts of these States that are not part of the river's drainage system but may benefit from water diverted from the system below Lees Ferry. For the purposes of roundtail chub, this includes three major river basins that drain into the Colorado River: the Little Colorado River, Bill Williams River, and Gila River (Figure C-2).

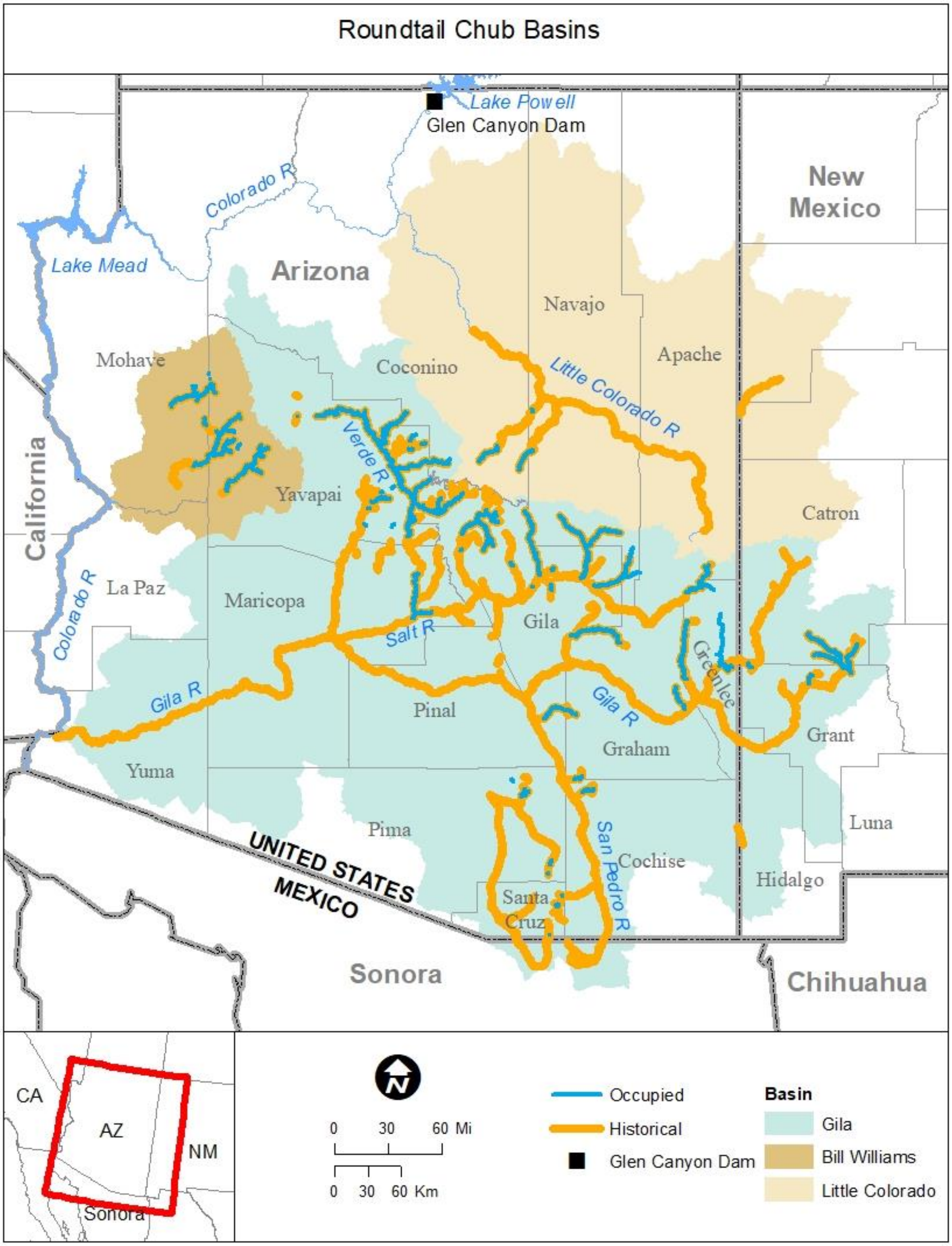


Figure C-2: Map of the lower Colorado River basin with the Little Colorado, Bill Williams, and Gila River watersheds highlighted. Includes is the historical and current occupied range based on the 3-Species georeferenced database. County, state, and national boundaries are included.

In 2009 and 2015, the U.S. Fish and Wildlife Service (FWS) issued separate listing determinations (74 FR 32352 and 80 FR 60754, respectively) regarding the roundtail chub in the Lower Basin, which was petitioned for listing as a Distinct Population Segment (DPS) (Center for Biological Diversity 2003). In both decisions, the FWS stated that the Upper and Lower Basins of the Colorado River were separate historically (due to distance), but that in more recent times that Glen Canyon Dam physically separates the two basins. Numerous authors have noted that roundtail chub was very rare with few documented records in the mainstem Colorado River between the Upper and Lower Basins (Minckley 1973, p. 102; Minckley 1979, p. 51; Bezzerides and Bestgen 2002, pp. 24–25; Voeltz 2002, pp. 19, 112). Gerber *et al*. (2001; pg. 2028), however, states that roundtail chub were once distributed throughout the entire Colorado River drainage. In the 2009 proposed rule, the FWS stated that measurable hydrographic differences between the Upper and Lower Basins of the Colorado River are evident, as are differences in the landscape-level roundtail chub habitats (ecoregions) (FR 74 32354), although these arguments were speculative.

The 2003 petition that spurred these listing decisions did not define the Lower and Upper Basins, but did explicitly state that the Little Colorado River, Bill Williams River, and Gila River portion of the species range warranted listing. Because of the petition and the traditional definition of Lower and Upper Basin, both listing decisions defined a Lower Colorado River DPS that included the Little Colorado River, Bill Williams River, and Gila River.

However, other lines of evidence suggest grouping roundtail chub from these three Lower Basin watersheds into a single unit may not reflect relevant biological and hydrological divisions for the species. We examined the available evidence to define our analysis area for this SSA, which was specific to the Lower Colorado River Basin.

C-2 Hydrological, biogeographical, and ecological divisions

The 2009 listing determination stated that the distance from Grand Falls (which is a 185 ft waterfall on the Little Colorado River, located 30 miles [mi] northeast of Flagstaff, AZ) to the mouth of the Escalante River (which contains the southernmost population of roundtail chub in the Upper Basin), is approximately 275 river mi (444 kilometers [km]) (via the Little Colorado River downstream to the mainstem Colorado River and upstream to the Escalante River) (Figure B-2). However, the distance from Grand Falls in the Little Colorado River to the confluence of the Bill Williams River (via the Little Colorado River downstream to the mainstem Colorado River and downstream to the confluence with the Bill Williams River) is 525.9 mi (846.4 km) and the distance from Grand Falls to the mouth of the Gila River (via the Little Colorado River downstream to the mainstem Colorado River and downstream to the confluence with the Gila River) is 684.5 mi (1101.6 km). The distance from the confluence of the Bill Williams River to the confluence of the Gila River is 158.6 mi (225.2 km). These river mile distances are taken from information calculated by the Bureau of Reclamation. Thus, by river distances, roundtail chub in the Little Colorado River are closer to the nearest populations in the Upper Basin than those in the Lower Basin.

Glen Canyon Dam currently separates fishes in the Upper and Lower Basins, but this feature has only been on the landscape for several decades. Historically, roundtail chub were believed to have occupied the mainstem Colorado River both upstream and downstream of the location of Glen Canyon Dam (Bezzerides and Bestgen 2002, pp. 24-30), including near the mouth of the Little Colorado River. However, there are fewer documented occurrences of roundtail chub from Glen Canyon (currently submerged by Lake Powell, which was created by Glen Canyon Dam) and the Grand Canyon (Bezzerides and Bestgen 2002, pp. 24). Numerous authors have noted that roundtail chub were absent or at low densities in the mainstem Colorado River downstream from the Grand Canyon to the Gulf of California. Based on these records, the distribution of roundtail chub was more likely continuous between the area now considered the Upper Basin and the Little Colorado River than between the Lower Basin and the Little Colorado River. The Grand Canyon has been noted as a biogeographic transition for other aquatic species (Smith 1978, p. 38) and is reflected in genetic studies of roundtail chub (see Chapter 2.1). Instead of Glen Canyon Dam, the Grand Canyon likely serves as a more logical demarcation in the distribution of roundtail chub, which would group Little Colorado River populations with those in the Upper Basin.

The Upper and Lower Basins cover different geographies that are influenced by contrasting environmental patterns. The Upper Basin drains the high peaks of the southern Rocky Mountains and flows primarily through the Colorado Plateau ecoregion (McMahon et al. 2001, entire), where the hydrograph is primarily driven by snowmelt. The Lower Basin primarily drains off the Mogollon Rim and Gila Mountains and drains through the Sonoran Desert ecoregion, where roundtail chub are primarily distributed in mid-elevation streams between 1,325 m (4,350 ft) and 2,000 m (6,570 ft) (Bestgen and Propst 1989; Voeltz 2002). Streams in the Lower Basin experience influx due to snowmelt, but at a substantially lower scale than Upper Basin streams. Furthermore, the Lower Basin receives contributions from the summer monsoons that are absent in the Upper Basin (Sheppard *et al*. 2002, p. 222; Hu and Feng 2007, p. 4706). Thus, both basins, and the roundtail chub that occupy them, are subjected to different environmental regimes.

The Little Colorado River lies at the boundary of these regions. It also is subjected to the southern monsoons typical of the southwestern United States but is on the leeward side of the Mogollon Rim. It is also within the Colorado Plateau ecoregion but at its southern-most extent. While there may be slight differences in the ecological settings between the Little Colorado River and the Lower Colorado River roundtail chub DPS and Upper Colorado River basin, these differences are not unique or unusual to the general ecology of the southwestern United States and not likely to be significant to the taxon.

C-3 Genetics

Morphologically, roundtail chub across the Colorado River Basin are designated a single species. However, genetic studies have revealed cryptic intraspecific divisions that correspond to geographic features. Several studies have shown that roundtail chub in the Lower and Upper Basin are genetically distinct, with populations in the Little Colorado River clustering with those in the Upper Basin (Schönhuth et al. 2014, pp. 216-217; Chafin *et al*. in press, pg. 7-11). In fact, Upper Basin roundtail chub appear to be more genetically similar to co-occurring *Gila* species (e.g. *G. cypha* and *G. elegans*) than Lower Basin roundtail chub. This may in part be due to hybridization: all *Gila* examined from the Little Colorado River population and the mainstem Colorado River and tributaries in the Upper Basin possess *G. cypha* or *G. elegans* mtDNA (Dowling and DeMarais 1993, pp. 444-446; Gerber *et al*. 2001, p. 2028). However, populations of the *G. robusta* complex of the Lower Basin in the Bill Williams and Gila River basins (including *G. robusta*, *G. intermedia*, and *G. nigra*) possess a unique, divergent mtDNA lineage that has not been found in either the Upper Basin or Little Colorado River (Dowling and DeMarais 1993, pp. 444-446; Gerber *et al.* 2001, p. 2028). Chafin *et al.* (2021, pp. 7-11) suggests the distinctness of roundtail chub in the Upper Basin and Little Colorado River is not due to hybridization with other *Gila* species. Regardless of the explanation, the evidence supports that roundtail chub in the Little Colorado River are genetically closer to roundtail chub in the Upper Basin than roundtail chub in the rest of the watersheds in the Lower Basin.

C-4 Conclusion

Based on our review, we do not find compelling evidence that roundtail chub in the Little Colorado River should be considered part of the Lower Basin distribution for the species. They are hydrologically and genetically more connected to populations in the Upper Basin. Ecologically the Little Colorado River does not fit with either the Upper or Lower Basin in terms of broad generalizations regarding environmental conditions. Therefore, our analysis area for this SSA will include roundtail chub in the Bill Williams and Gila River basins, which is based on their genetic, hydrological, and environmental similarity.

APPENDIX D: EXTIRPATED AND HISTORICAL STREAMS

Extirpated - we define *extirpated* as a population that has not been detected in the past 50 years. This definition was adapted from the definition of *extinct* adopted by the American Fisheries Society (AFS; Jelks et al. 2008), which refers to a taxon (e.g., species) of which no living individual has been documented in its natural habitat for 50 or more years. However, because the sampling effort involved in detecting the presence of a rare species within a wide and complex distribution can be much greater than for a single population with a restricted and simple distribution, we have defined several instances where the 50-year detection criterion may be relaxed when declaring a population extirpated:

(E-1) the population has not been detected in the past 50 years;

(E-2) the population has not been detected in presence/absence surveys conducted expansively (across the entire distribution of the population), intensively (sampling all suitable habitats), and effectively (suitable habitats were sampled with appropriate gears) over a minimum period of 10 consecutive years or 10 surveys in total if not sampled in consecutive years;

(E-3) a known catastrophic event such as a chemical spill, wildfire, or desiccation occurred that eliminated the population. In this case, a single expansive survey of the population range post-event would be sufficient to conclude extirpation; or

(E-4) the population was intentionally removed from the wild and placed into managed refuges in an attempt to salvage its genetic legacy in the face of severe population decline and apparent imminent extirpation.

Table D-1. Extirpation Criteria E-1; the population has not been detected in the past 50 years.

Stream Name	Last Confirmed Survey Year (Source)	Extirpation Criteria Number
Christopher Creek	1935 (Madsen 1935)	E-1
Horton Creek	1935 (Madsen 1935)	E-1
Bill Williams River	1970 (ASU 5896)	E-1
Lower Gila River	1943 (UMMZ 146666)	E-1
San Pedro River	1931 (NMNH 130207)	E-1
Agua Fria River	1966 (Rinne 1969)	E-1
Fish Creek	1965 (ASU 2246)	E-1
Haunted Canyon	1959 (UMMZ 176179)	E-1
Babocomari River	1968 (ASU 4845)	E-1
Monkey Spring	1967 (ASU 4849)	E-1
Apache Creek, NM	1872 (ANSP 20448)	E-1

Stream Name	Last Confirmed Survey Year (Source)	Extirpation Criteria Number
Arnett Creek	1945 (SMNH 132268)	E-1
Duck Creek, NM	Pre-1900 (ANSP 19452)	E-1
Queen Creek	1938 (UMMZ 125041)	E-1
San Simon Cienega	1939 (UMMZ 137093)	E-1
Big Chino Wash	1950 (UMMZ 162834)	E-1
Sharp Creek	1935 Madsen	E-1
Beaver Creek (Upper Gila)	1949 (MSB 2007)	E-1
Taylor Creek, NM	1937 (UMMZ 118180)	E-1
Dry Beaver Creek (Verde)	1956 (UA 95-213)	E-1

Table D-2. Extirpated Criteria E-2; the population has not been detected in presence/absence surveys conducted expansively (across the entire distribution of the population), intensively (sampling all suitable habitats), and effectively (suitable habitats were sampled with appropriate gears) over a minimum period of 10 consecutive years or 10 surveys in total if not sampled in consecutive years.

Stream Name	Last Confirmed Survey Year (Source)	Extirpation Criteria Number
Rye Creek	1995 (Weedman 1996)	E-2
Dry Beaver Creek	1972 (Girmendonk and Young 1997)	E-2
Cave Creek/Seven Springs Wash	1978 (ASU 7764)	E-2
Santa Cruz River	1977 (ASU 7143)	E-2
Tularosa River, NM	Pre 1990 (ANSP 19449)	E-2
Turkey Creek	2006 (Carter et al. 2007)	E-2
Post Canyon	1989 (Weedman et al. 1996)	E-2

Table D-3. Extirpation Criteria E-4; the population was intentionally removed from the wild and placed into managed refuges in an attempt to salvage its genetic legacy in the face of severe population decline and apparent imminent extirpation.

Stream Name	Last Confirmed Survey Year (Source)	Extirpation Criteria Number
T4 Springs	2009 (Robinson 2010)	E-4

Table D-4. Unknown; Extirpation survey requirement not met. We do not know if these areas are currently occupied by roundtail chub.

Stream Name	Last Confirmed Survey Year (Source)	Status
Deadman/ Deadman Creek	2002 (Bagley 2002)	Unknown
Cienega Los Fresnos (Mexico)	1990 (Varela-Romero et al. 1992)	Unknown
Mineral Creek	2000 (Robinson et al. 2010)	Unknown
Cedar Creek	1986 (ASU 11974)	Unknown
Salome Creek	Voeltz 2002 (ASU 18304)	Unknown
South Fork Deadman Creek	2002 (Bagley 2002)	Unknown

Table D-5. Historical streams without source information. These streams were identified in the Historical layer of the Database. Although records are not available for these streams we assume roundtail chub may have historically occupied these areas based on location, presence of water, and connectivity to other historically occupied streams.

Stream Name (HUC06)	Stream Length (km)
Ash Creek (Lower Agua Fria)	18
Little Ash Creek (Lower Agua Fria)	9
Hunter Creek	4
Pinto Creek	35
Wood Creek	3
Deer Creek	7
El Pantano	4
La Calera	25
Las Pilas	9
San Rafael	20
Wildcat Canyon	2
Cherry Creek (Santa Cruz)	13
Pantano Wash	35
Rillito River	19
Sonoita Creek	42
Tanque Verde Wash	5
Burnt Corral Canyon, NM	3
Diamond Creek, NM	2
Iron Creek, NM	2
Sacaton Creek, NM	7
South Fork Ash Creek	7
Chase Creek	4
Ellison Creek	13
West Fork Sycamore Creek	8

APPENDIX E: LIST OF STREAMS CURRENTLY OCCUPIED BY ROUNDTAIL CHUB IN THE LOWER COLORADO RIVER BASIN AND ASSOCIATED MAPS.

Streams have been grouped by HUC6 units. See Chapter 5 of the report for details about the specific metrics compiled in the tables. Note that for the Nonnative Community, the categories have been recoded for this table. The High category equals a 3, Medium a 2, Low a 1, and None (N/A).

E-1 Bill Williams River Watershed (HUC6)

Population Name (cp#)	Stream Name (PMU)	State	Occupied Stream Length (KM)	Population Stream Length (KM)	Nonnative Community	Population Stability
Ash Creek (cp0106)	East Ash Creek	AZ	2.69	7.13	0	1
	Ash Creek (1)	AZ	4.44		0	1
Trout Creek (cp0105)	Gonzales Wash	AZ	3.28	75.82	0	1
	McGee Wash	AZ	3.26		0	1
	Ash Creek (2)	AZ	5.10		3	1
	Cow Creek	AZ	7.18		0	1
	Fork Rock Creek (3)	AZ	2.39		0	1
	Trout Creek	AZ	54.62		3	1
Boulder Creek (cp0110)	Boulder Creek (1)	AZ	0.92	0.92	1	1
Boulder Creek (cp0111)	Boulder Creek (2)	AZ	4.37	4.37	1	1
Boulder Creek (cp0109)	Wilder Creek	AZ	14.18	29.39	0	1
	Stone Corral Canyon	AZ	4.29		0	1
	Boulder Creek (3)	AZ	10.92		1	1
Francis Creek (cp0112)	Francis Creek (1)	AZ	10.07	10.07	0	1
Pine-Burro (cp0107)	Burro Creek (1)	AZ	8.03	11.98	1	1
	Pine Creek	AZ	3.95		0	1
Burro Creek (cp0108)	Francis Creek (2)	AZ	4.40	93.07	3	1
	Conger Creek (1)	AZ	9.59		0	1
	Burro Creek (2)	AZ	67.54		3	1
	Boulder Creek (4)	AZ	10.43		3	1
	Conger Creek (4)	AZ	1.12		3	1

Population Name (cp#)	**Stream Name (PMU)**	**State**	**Occupied Stream Length (KM)**	**Population Stream Length (KM)**	**Nonnative Community**	**Population Stability**
Cottonwood Wash (cp0113)	Cottonwood Wash (1)	AZ	1.81	1.81	3	1
Santa Maria River (cp0114)	Cottonwood Wash (2)	AZ	6.82		3	1
	Smith Canyon	AZ	8.57		0	1
	Sycamore Creek	AZ	20.06		3	1
	Kirkland Creek	AZ	12.51		3	4
	Santa Maria River	AZ	38.26	86.22	3	4
Fork Rock Creek*	Fork Rock Creek (1)	AZ	0.54	0.54	0	1
Fork Rock Creek*	Fork Rock Creek (2)	AZ	0.84	0.84	0	1

* Indicates PMUs that do not meet criteria for population designation because evidence of all life stages has not been documented.

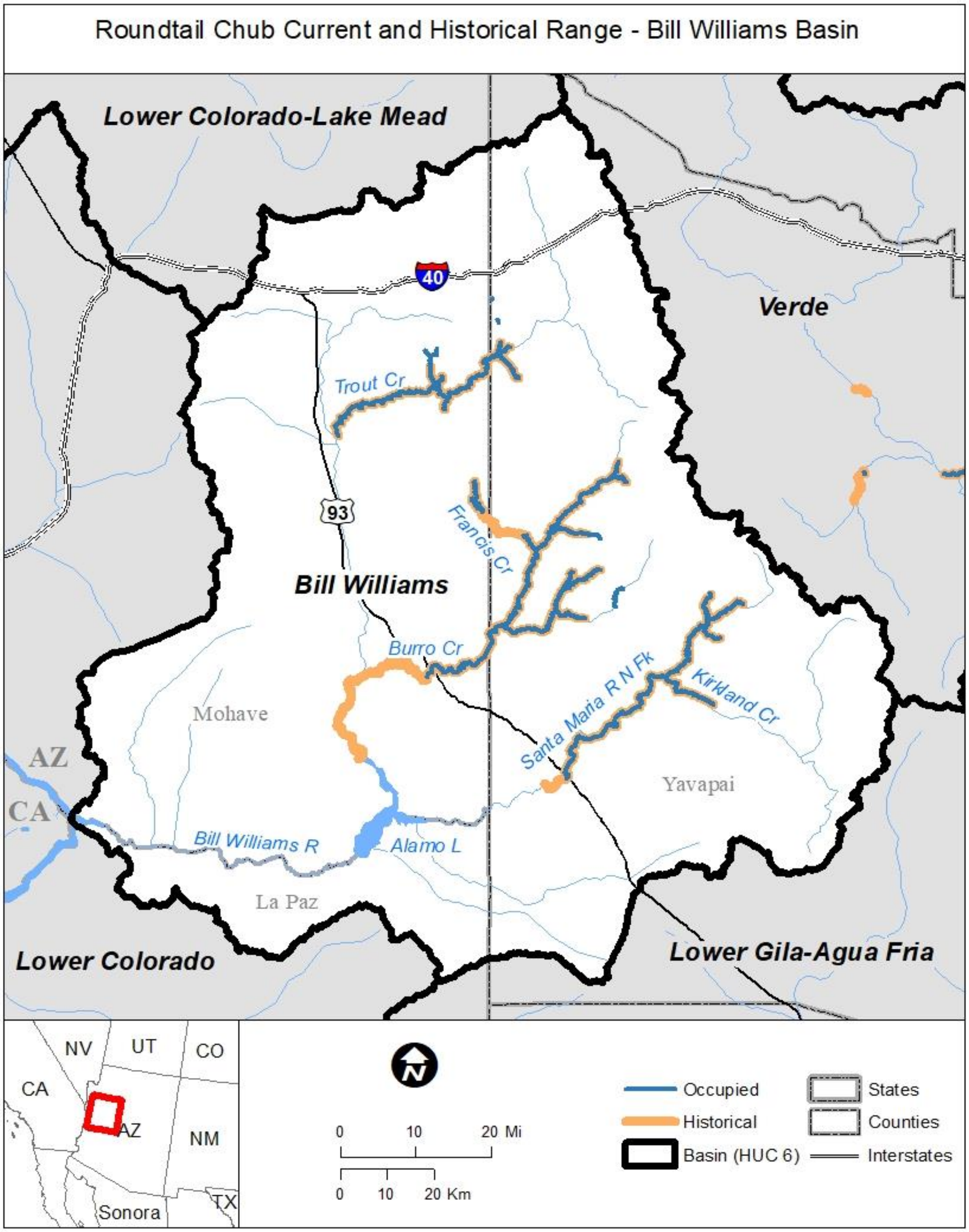


Figure E-1: Map of the historical and current occupied range of roundtail chub in the Bill Williams HUC6 basin based on the 3-Species Rangewide geospatial database.

E-2 Lower Gila-Agua Fria River Watershed (HUC6)

Population Name (cp#)	Stream Name (PMU)	State	Occupied Stream Length (KM)	Population Stream Length (KM)	Nonnative Community	Population Stability
Larry Creek (cp0033)	Larry Creek	AZ	0.53	0.53	0	1
Lousy Canyon (cp0034)	Lousy Canyon	AZ	0.53	0.53	0	1
Silver Creek (cp0035)	Silver Creek	AZ	2.06	2.06	1	3
Indian Creek (cp0036)	Indian Creek (1)	AZ	7.99	11.81	0	1
	Indian Creek (2)	AZ	3.82		0	1
Sycamore Creek (cp0037)	Little Sycamore Creek	AZ	1.35	7.15	0	1
	Sycamore Creek (1)	AZ	0.29		1	1
	Sycamore Creek (2)	AZ	5.50		1	4

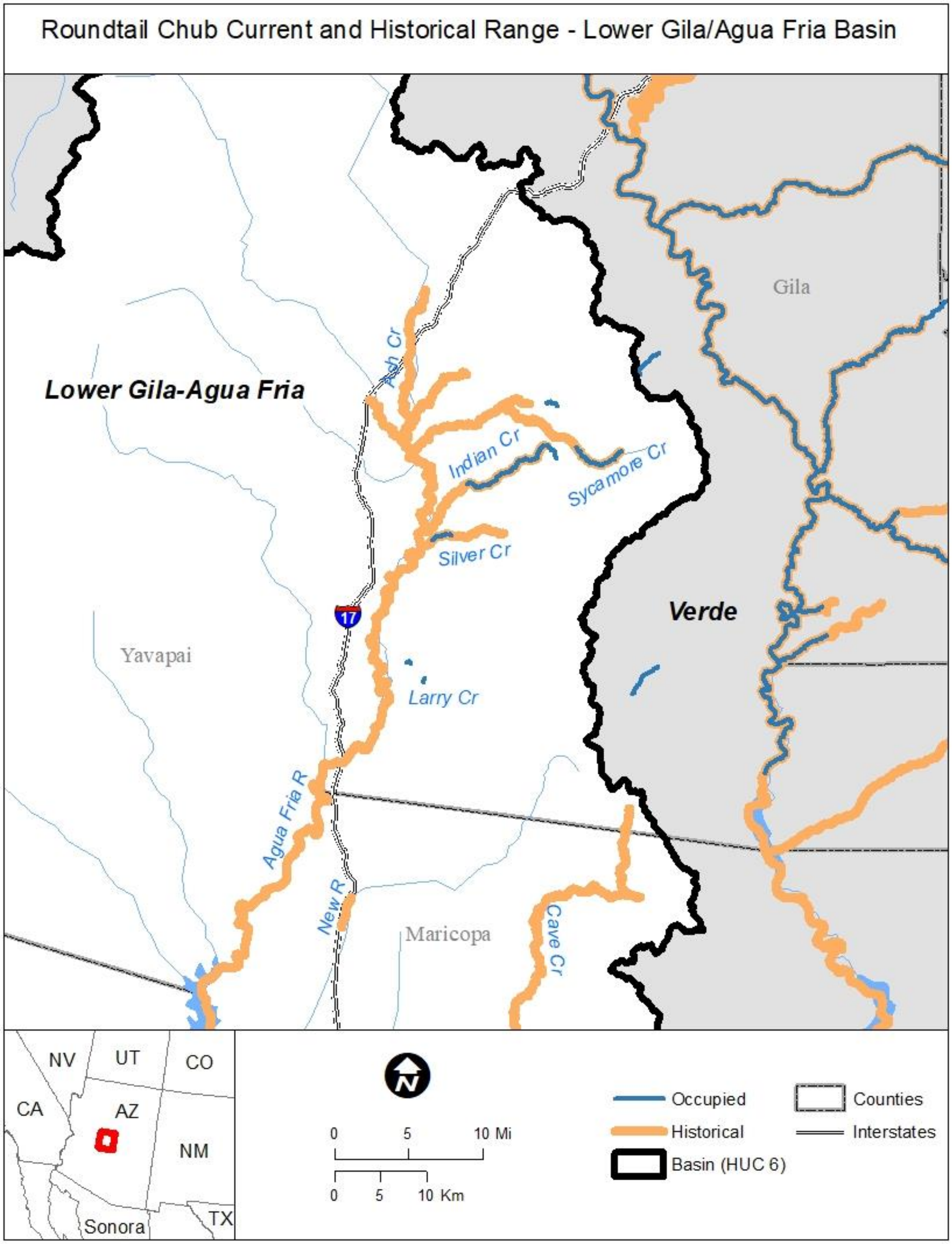


Figure E-2: Map of the historical and current occupied range of roundtail chub in the Lower Gila-Agua Fria HUC6 basin based on the 3-Species Rangewide geospatial database.

E-3 Salt River Watershed (HUC6)

Population Name (cp#)	Stream Name (PMU)	State	Occupied Stream Length (KM)	Population Stream Length (KM)	Nonnative Community	Population Stability
Upper Tonto (cp0029)	Rock Creek (1)	AZ	0.41	103.14	0	1
	Haigler Creek	AZ	13.14		3	1
	Tonto Creek	AZ	25.81		3	1
	Gordon Canyon Creek	AZ	6.39		1	1
	Spring Creek (and Dinner Creek)	AZ	31.69		3	1
	Rock Creek (2)	AZ	13.57		3	1
	Buzzard Roost Canyon	AZ	1.67		3	1
	Marsh Creek	AZ	10.47		3	1
Black River (cp0030)	Beaver Creek	AZ	14.76	64.03	2	1
	Boneyard Creek (and N. Fork E. Fork Black River)	AZ	13.54		2	1
	East Fork Black River	AZ	12.66		2	1
	Black River (and W. Fork Black River)	AZ	23.07		3	1
Gun Creek (cp0064)	Gun Creek	AZ	0.62	0.62	3	1
Tonto Creek (cp0065)	Tonto Creek	AZ	8.86	8.86	3	3
Cherry Creek (cp0066)	Cherry Creek	AZ	3.55	3.55	3	1
Salt River (cp0067)	Salt River (1)	AZ	1.37	1.37	3	4
Salt River (cp0076)	Salt River (2)	AZ	16.45	21.94	3	1
	Salt River (3)	AZ	5.49		3	1
Ash Creek (cp0068)	Ash Creek	AZ	5.13	5.13	0	1
West Fork Black River*	West Fork Black River	AZ	1.20	1.20	2	N/A
White River (cp0988)	White River	AZ	29.10	70.00	3	1
	North Fork White River	AZ	24		0	1

Population Name (cp#)	Stream Name (PMU)	State	Occupied Stream Length (KM)	Population Stream Length (KM)	Nonnative Community	Population Stability
	East Fork White River	AZ	16.90		0	1
Corduroy Creek (cp0987)	Corduroy Creek	AZ	42.00	123.30	3	1
	Carrizo Creek	AZ	81.30		3	1
Cibecue Creek (cp0983)	Cibecue Creek (below barrier)	AZ	2.60	2.60	0	4
Canyon Creek (cp0982)	Canyon Creek	AZ	71.60	71.60	0	4

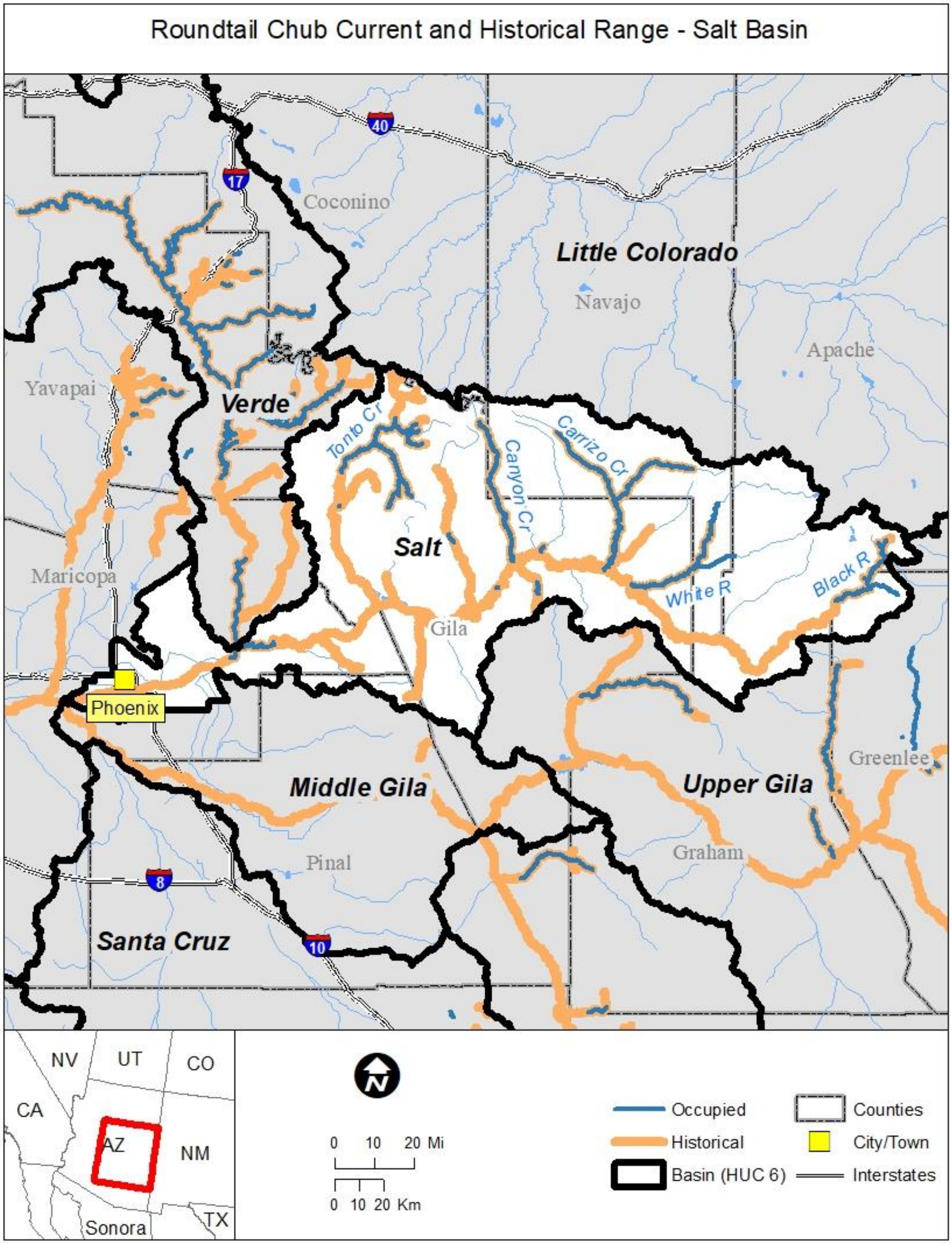


Figure E-3: Map of the historical and current occupied range of roundtail chub in the Salt HUC6 basin based on the 3-Species Rangewide geospatial database.

E-4 San Pedro River Watershed (HUC6)

Population Name (cp#)	Stream Name (PMU)	State	Occupied Stream Length (KM)	Population Stream Length (KM)	Nonnative Community	Population Stability
Aravaipa Creek (cp0055)	Aravaipa Creek	AZ	37.42	37.42	3	1
Hot Springs Canyon (cp0056)	Bass Canyon (1)	AZ	2.67	14.92	0	1
	Bass Canyon (2)	AZ	1.04		0	1
	Bass Canyon (3)	AZ	0.97		0	1
	Double R Canyon	AZ	0.48		0	1
	Hot Springs Canyon (1)	AZ	7.24		0	1
	Hot Springs Canyon (2)	AZ	2.52		0	1
Redfield Canyon (cp0058)	Redfield Canyon (1)	AZ	0.95	0.95	0	1
Redfield Canyon (cp0057)	Redfield Canyon (2)	AZ	1.09	9.06	3	1
	Redfield Canyon (3)	AZ	5.22		3	1
	Redfield Canyon (4)	AZ	0.27		3	1
	Redfield Canyon (5)	AZ	2.48		3	1
O'Donnell Canyon (cp0061)	O'Donnell Canyon (1)	AZ	0.61	0.61	1	1
O'Donnell Canyon (cp0062)	O'Donnell Canyon (2)	AZ	1.81	1.81	1	1
O'Donnell Canyon (cp0063)	O'Donnell Canyon (3)	AZ	0.90	0.90	3	4
O'Donnell Canyon (cp0059)	O'Donnell Canyon (4)	AZ	0.13	0.13	1	1

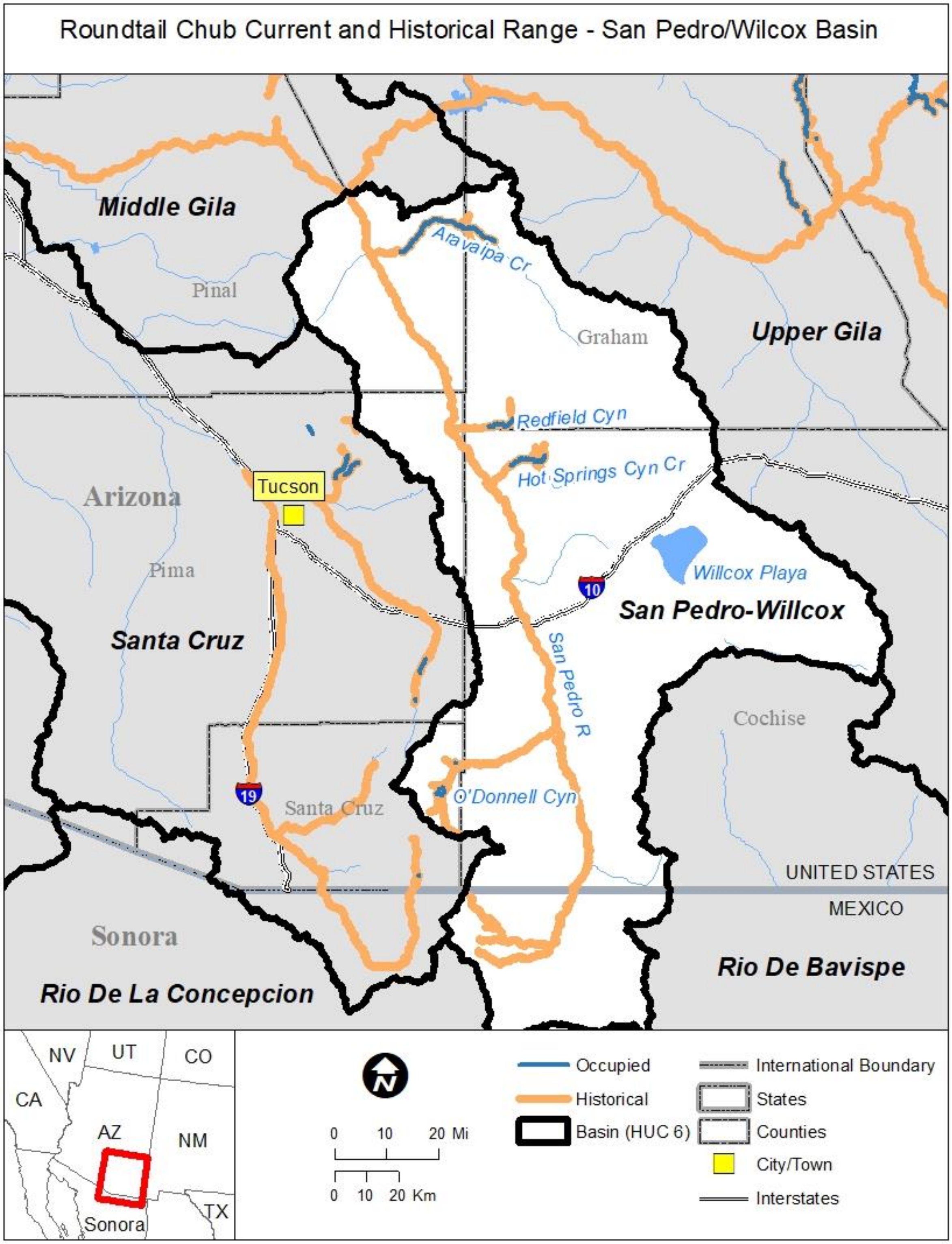


Figure E-4: Map of the historical and current occupied range of roundtail chub in the San Pedro-Wilcox HUC6 basin based on the 3-Species Rangewide geospatial database.

E-5 Santa Cruz River Watershed (HUC6)

Population Name (cp#)	Stream Name (PMU)	State	Occupied Stream Length (KM)	Population Stream Length (KM)	Nonnative Community	Population Stability
Bear Canyon (cp0028)	Bear Canyon (1)	AZ	4.19	4.19	0	1
Bear Canyon*	Bear Canyon (2)	AZ	1.90	1.90	0	N/A
Sheehy Spring (cp0069)	Sheehy Spring	AZ	0.16	0.16	1	1
Sabino Creek (cp0071)	Sabino Creek (1)	AZ	2.13	2.13	0	1
Sabino Creek (cp0070)	Sabino Creek (2)	AZ	6.05	6.05	0	1
Sabino Creek (cp0072	Sabino Creek (3)	AZ	0.66	0.66	0	1
Romero Canyon (cp0073)	Romero Canyon (1)	AZ	0.35	0.35	0	4
Romero Canyon (cp0074)	Romero Canyon (2)	AZ	1.10	1.10	0	1
Romero Canyon (cp0075)	Romero Canyon (3)	AZ	1.86	1.86	0	1
Cienega Creek (cp0079)	Cienega Creek (1)	AZ	0.75		0	1
	Cienega Creek (2)	AZ	4.17		0	1
	Mattie Canyon	AZ	0.77	5.69	0	1

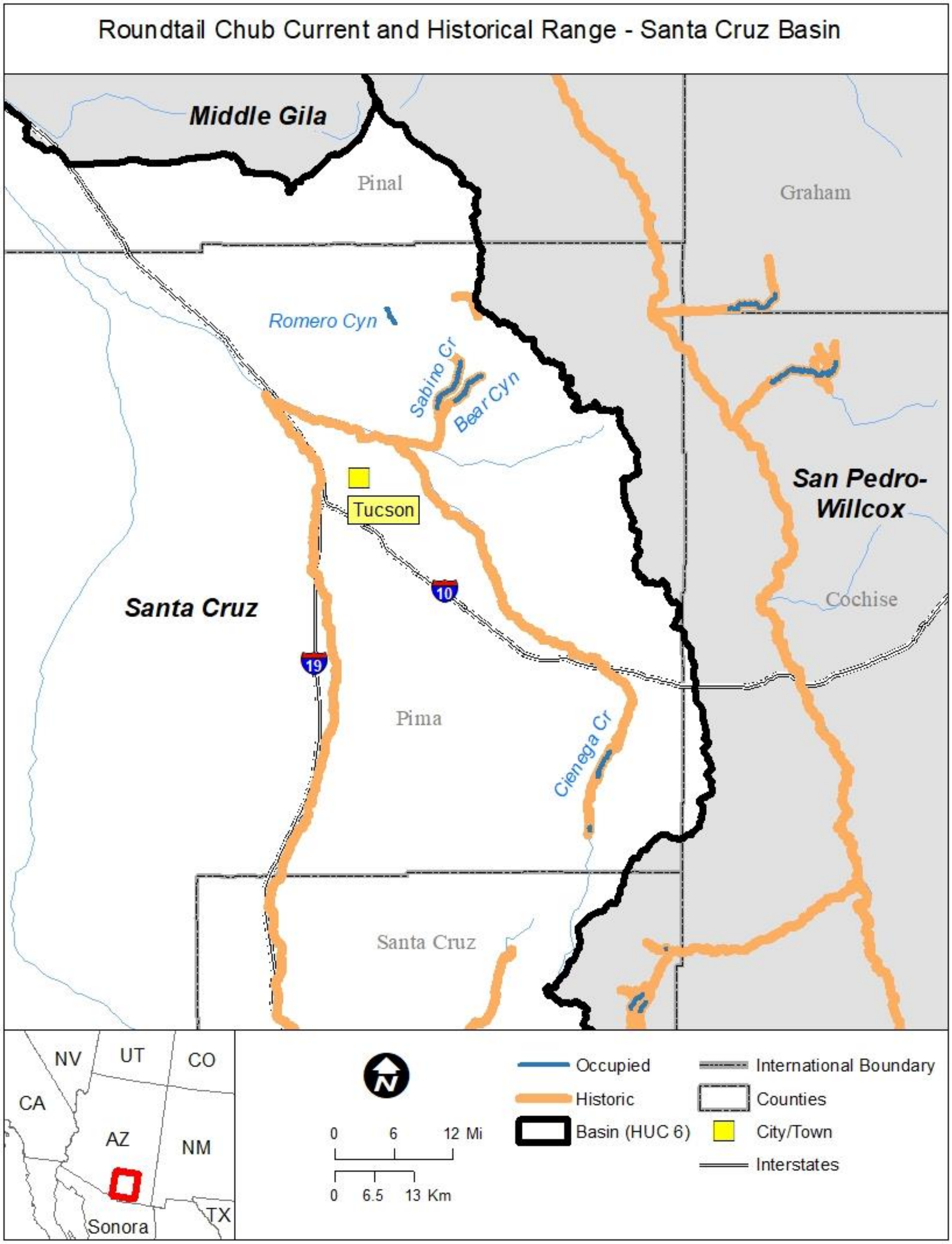


Figure E-5: Map of the historical and current occupied range of roundtail chub in the Santa Cruz HUC6 basin based on the 3-Species Rangewide geospatial database.

E-6 Upper Gila River Watershed (HUC6)

Population Name (cp#)	Stream Name (PMU)	State	Occupied Stream Length (KM)	Population Stream Length (KM)	Nonnative Community	Population Stability
Blue River (cp0038)	Blue River (1)	AZ	5.20	51.36	2	1
	Blue River (2)	AZ	27.53		1	1
	Blue River (3)	AZ	18.63		0	1
Blue River*	Blue River (4)	AZ	0.79		3	N/A
Dix Creek (cp0040)	Dix Creek	AZ	5.97	6.83	0	1
	Right Prong Dix Creek	AZ	0.86		0	1
Harden Cienega Creek (cp0041)	Harden Cienega Creek (1)	AZ	1.20	3.47	3	1
	Harden Cienega Creek (2)	AZ	2.26		3	1
Bonita Creek (cp0044)	Bonita Creek (1)	AZ	15.11	19.43	1	1
	Bonita Creek (2)	AZ	4.32		1	1
Eagle Creek (cp0054)	Eagle Creek (1)	AZ	15.42	47.91	1	2
	Eagle Creek (2)	AZ	47.91		3	2
San Francisco River*	San Francisco River	AZ	7.31	7.31	3	N/A
Lazy YJ Ranch Pond*	Lazy YJ Ranch Pond	AZ	0.00	0.00	0	N/A
Pigeon Creek*	Pigeon Creek	AZ	0.06	0.06	0	N/A
San Carlos River	San Carlos River	AZ	33.16	58.94	3	4
	Ash Creek	AZ	25.78		3	4
Middle Fork Gila River (cp0045)	Middle Fork Gila River (1)	NM	36.39	148.87	3	1
	Middle Fork Gila River (2)	NM	24.42		3	1
	West Fork Gila River (1)	NM	29.87		2	1
	West Fork Gila River (2)	NM	3.88		3	1
	West Fork Gila River (3)	NM	4.57		3	1
	East Fork Gila River	NM	45.19		3	1

Population Name (cp#)	Stream Name (PMU)	State	Occupied Stream Length (KM)	Population Stream Length (KM)	Nonnative Community	Population Stability
	Black Canyon Creek (1)	NM	0.99		2	1
	Black Canyon Creek (2)	NM	3.57		2	1
Mule Creek (cp0031)	Mule Creek	NM	5.13	5.13	3	1
Turkey Creek (cp0032)	Sycamore Canyon	NM	1.45	10.96	1	1
	Turkey Creek	NM	9.51		1	1
Knight Canyon*	Knight Canyon	AZ	3.1	3.1	3	N/A
Middle Prong Creek*	Middle Prong Creek	AZ	2.0	2.0	1	N/A

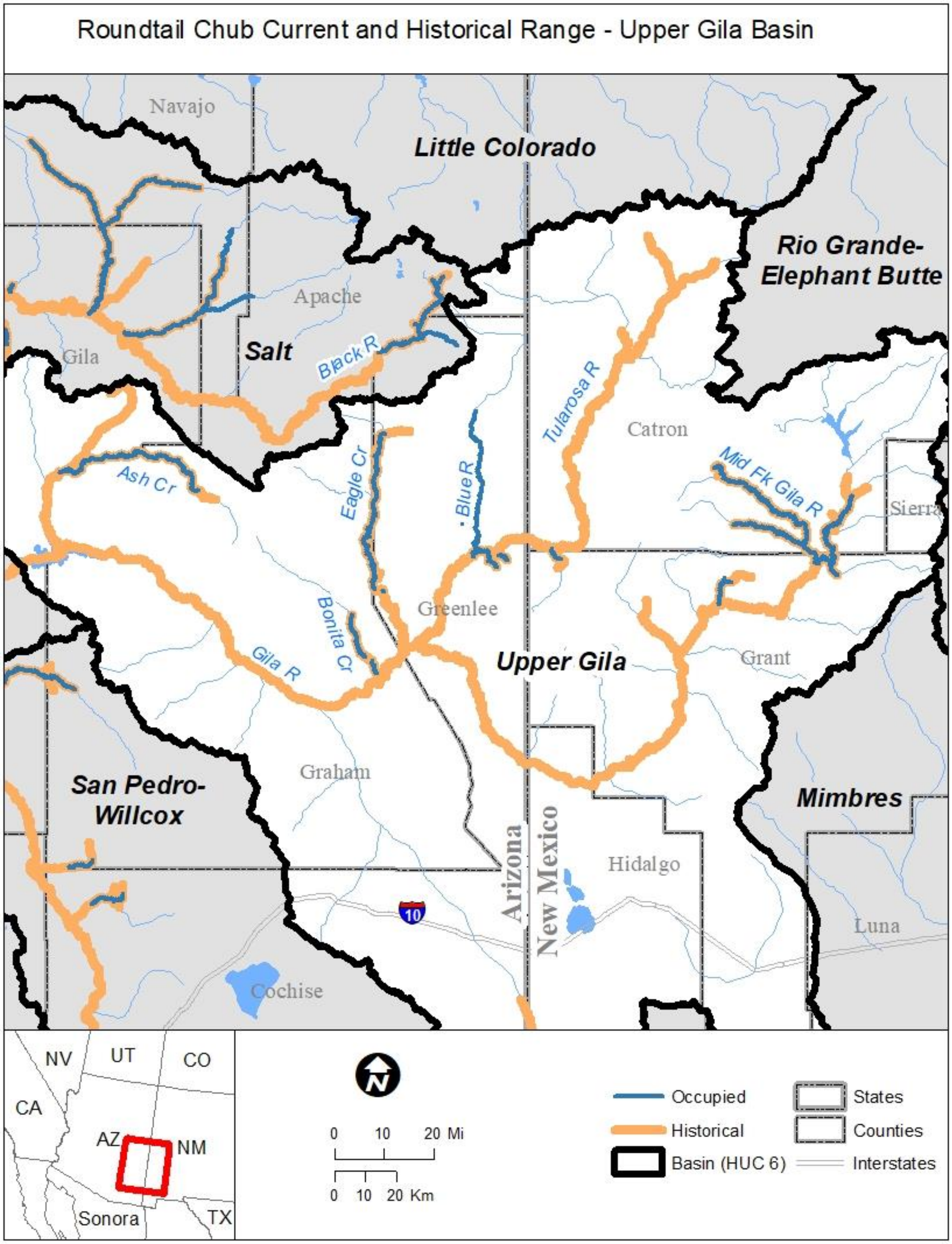


Figure E-6: Map of the historical and current occupied range of roundtail chub in the Upper Gila HUC6 basin based on the 3-Species Rangewide geospatial database.

E-7 Verde River Watershed (HUC6)

Population Name (cp#)	Stream Name (PMU)	State	Occupied Stream Length (KM)	Population Stream Length (KM)	Nonnative Community	Population Stability
Verde River*	Verde River (1)	AZ	2.5	2.5	3	N/A
Verde River (cp0042)	Webber Creek	AZ	1.51	427.50	1	4
	Rock Creek	AZ	1.82		3	1
	The Gorge	AZ	1.58		3	1
	Pine Creek	AZ	13.53		3	2
	East Verde River (1)	AZ	16.51		3	1
	East Verde River (2)	AZ	50.27		3	4
	East Verde River (3)	AZ	5.60		3	4
	Verde River (2)	AZ	14.06		3	1
	Verde River (3)	AZ	23.28		3	1
	Verde River (4)	AZ	22.96		3	1
	Verde River (5)	AZ	77.22		3	1
	Verde River (6)	AZ	27.37		3	1
	Verde River (7)	AZ	17.40		3	1
	Verde River (8)	AZ	38.81		3	1
	West Clear Creek (2)	AZ	29.44		3	1
	Wet Bottom Creek	AZ	5.73		3	1
	Fossil Creek (5)	AZ	7.34		3	1
	Oak Creek	AZ	63.56		3	3
	Canyon Creek	AZ	2.57		3	1
	Sycamore Creek	AZ	6.92		3	1
Verde River (cp0076)	Verde River (9)	AZ	39.91	39.91	3	1
Spring Creek (cp0043)	Spring Creek	AZ	4.86	4.86	3	1
Fossil Creek (cp0046)	Fossil Creek (1)	AZ	5.23	5.23	0	1
Fossil Creek (cp0047)	Fossil Creek (2)	AZ	3.70	3.70	0	1
Fossil Creek (cp0048)	Fossil Creek (3)	AZ	2.03	2.03	0	1
Fossil Creek (cp0049)	Fossil Creek (4)	AZ	9.52	9.52	0	1

Population Name (cp#)	Stream Name (PMU)	State	Occupied Stream Length (KM)	Population Stream Length (KM)	Nonnative Community	Population Stability
West Clear Creek (cp0050)	West Clear Creek (1)	AZ	30.22	30.22	2	1
Willow Valley (cp0051)	Willow Valley	AZ	5.62	5.62	2	1
Walker Creek (cp0052)	Walker Creek	AZ	3.52	3.52	0	1
Wet Beaver Creek (cp0053)	Wet Beaver Creek	AZ	3.86	3.86	3	1
Roundtree Canyon (cp0060)	Roundtree Canyon	AZ	3.98	3.98	0	1
Williamson Valley Wash (cp0077)	Williamson Valley Wash	AZ	0.66	0.66	1	4
Red Tank Draw (cp0080)	Red Tank Draw	AZ	2.57	2.57	3	1
Gap Creek (cp0083)	Gap Creek (1)	AZ	0.92	0.92	0	1
Gap Creek (cp0082)	Gap Creek (2)	AZ	1.80	1.80	0	1
Gap Creek (cp0081)	Gap Creek (3)	AZ	0.35	0.35	0	4
Rarick Canyon*	Rarick Canyon	AZ	3.37	3.37	1	N/A
LO Pocket Tank*	LO Pocket Tank	AZ	0.00	0.00	0	N/A

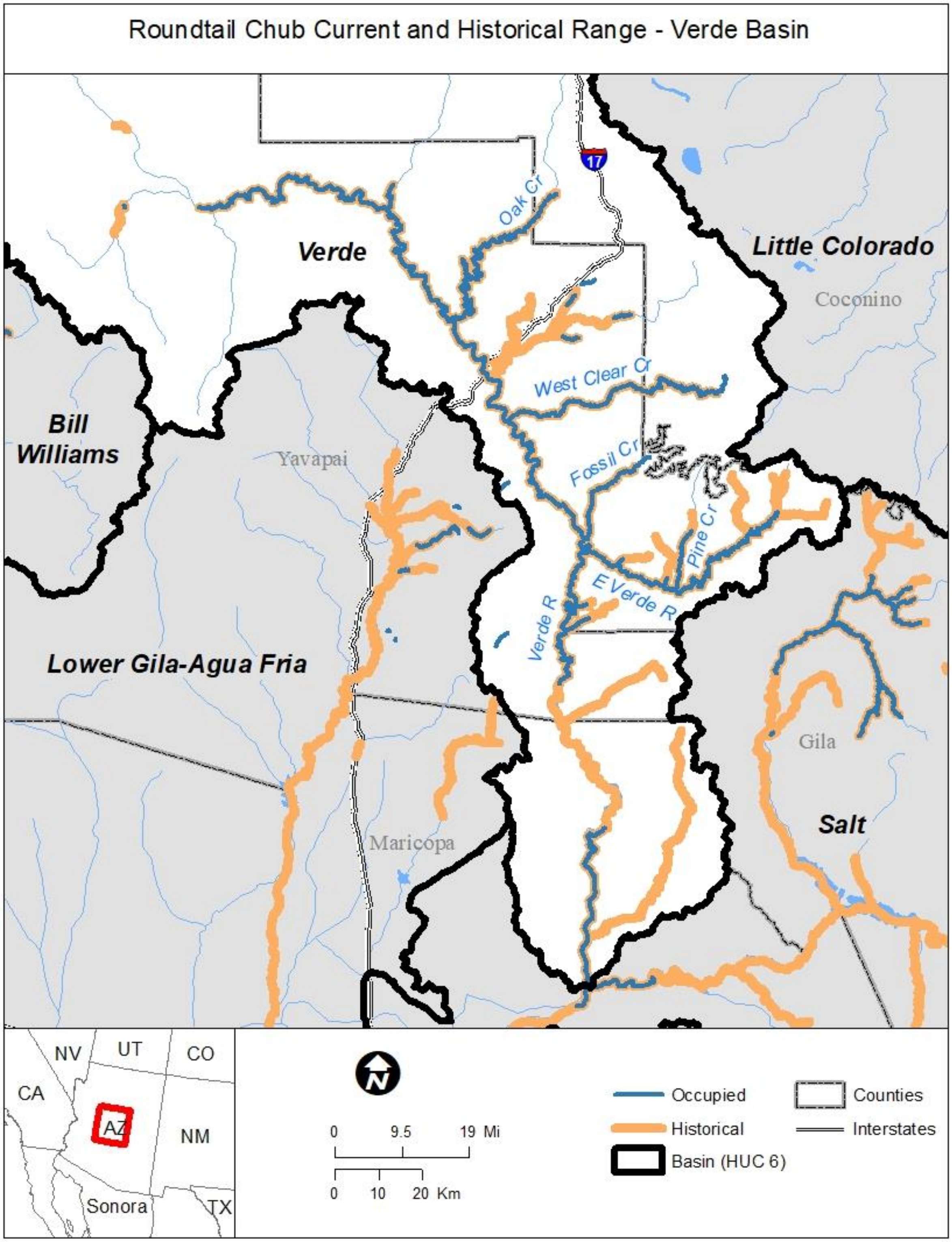


Figure E-7: Map of the historical and current occupied range of roundtail chub in the Verde HUC6 basin based on the 3-Species Rangewide geospatial database.

APPENDIX F: OCCUPANCY MODEL DESCRIPTION

Introduction

We built a site occupancy based predictive model in support of the species status assessment for the roundtail chub that occur in 159 stream segments (or population management units (PMUs), hereafter referred to as streams or sites in this report) where they currently reside within six watersheds of the lower Colorado River basin in Arizona and New Mexico. The model projects the future site occupancy as either presence or absence using replicated, stochastic Bernoulli trials for each stream with site-specific probability of remaining occupied (i.e., persistence probability) based on the conditions measured and projected changes at each stream. We also incorporated recolonization functions to allow sites that become extirpated within the model projection to be recolonized naturally if the stream is connected to other extant sites or recolonized through active management of restocking extirpated sites. Our model tracks and stochastically varies conditions at each stream over time to account for future variability and uncertainty in current conditions and their effects on chub persistence. Specifically, conceptual modeling identified three primary influences on chub survival and reproduction: the presence of exotic competitors and predators (i.e., nonnative community); the length of an occupied stream segment; and the frequency of beneficial floods. The model tracks the nonnative community as a stochastic categorical variable, the time between beneficial floods, and the length of each stream over time. We incorporated into the model directional changes (i.e., increases or decreases) for each of these three factors to account for environmental stochasticity, increasing threats (e.g., effects of climate change), and ongoing and future management efforts for the species.

Here we describe the model structure, site occupancy and conditions dynamics, the statistical distributions used to account for uncertainty and variability, and the results of sensitivity analyses and specific modeling scenarios that capture possible future conditions based on the number of projected occupied streams over time within each watershed across the chub's range within the lower Colorado River basin.

Model description

We developed a simulation model in program R that incorporated environmental stochasticity and used the model to run 500 replicated time series for multiple scenarios. Our model to predict future status of the species is a site occupancy model that used first order Markovian processes to predict chub presence in a stream at time t+1 based on presence at time t and a binomial probability Bernoulli trial:

$$Presence_{t+1} \sim binomial(1,P_{p,t}) \qquad (1)$$

Where, $P_{p,t}$ is the probability of persistence within a stream given that chub were present at time t. The dynamics and parameterization of the model were expert driven (see Expert Elicitation section below). That is, we worked with experts to conceptualize the system dynamics and understand what factors would increase or decrease persistence probability at chub-occupied streams (Figure F-1). Experts asserted that in the absence of other threats, natural annual persistence probability (P_N) would be very high, close to 1.0. So, we set natural persistence probability at ~0.999, meaning that under pristine conditions a local chub population would have a 99.9% chance of persisting within each stream each year. Thus, the notation for the core projection model was updated as:

$$Presence_{t+1} \sim binomial(1,P_{N,t}) \qquad (2)$$

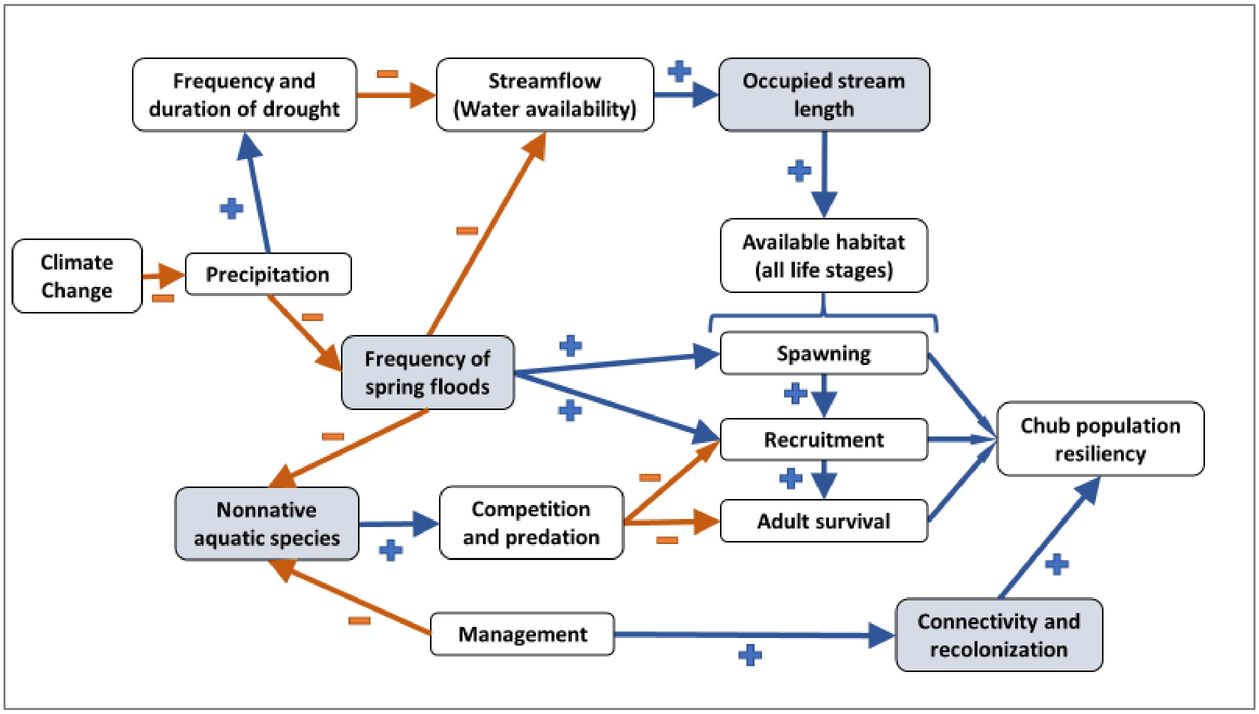


Figure F-1: Conceptual ecological model for roundtail chubs. Dark boxes indicate parameters in the occupancy model.

Many of the streams occupied by chubs have various limitations on meeting the ecological needs of chubs. The conceptual modeling effort identified the presence of nonnative species, especially predators such as green sunfish and smallmouth bass, the size of a stream, and the frequency of beneficial floods at a stream as negatively influencing chub persistence within a stream (Figure F-1 and F2). That is, the nonnative community, the length of a stream, and the time since the last beneficial floods are likely important factors for persistence probability. In other words, as these stream conditions change the resiliency of the chub populations within these stream segments likely change as does their probability of extirpation. Therefore, we designed the model to keep track of these three factors and then modify the P_N at each stream depending on the annual site-specific conditions. Thus, the stream persistence model was updated as:

$Presence_{t+1} \sim binomial(1, P_{R,i,t})$

Where $P_{R,i,t}$ is the realized persistence probability at each stream, *i*, in each year, *t*. The parameter P_R was the natural persistence probability (P_N) reduced by the effects of the exotic community (E), the time since the last flood (F), and the size/length of the stream (S), as follows:

$$P_{R,i,t} = P_N - E_{i,t} - F_{i,t} - S_{i,t} \quad (3)$$

In the model, P_N was set to 0.9999 for all streams as the natural probability of persistence of chubs in a stream without the ecological or anthropogenic stresses.

Expert elicitation methods and results

The effect of each stressor PN was formally elicited from a team of nine species and ecological experts using formal 4-point elicitation methods and Del Phi approaches to elicit values and variability among experts. The specific methodology and results of the elicitation process, carried out in 2016, are described fully in Appendix X. In a workshop format, we used a series of questions to elicit the risk of extirpation over a 10-year period of streams in certain conditions. We asked the questions assuming effects of independent factors, and we asked respondents to assume other factors were ‘average conditions,’ there were no active management, and that normal stochastic processes were acting on the species. The results of the questions formed the basis relating the stream conditions to probability of persistence over time.

At the time of the elicitation, we anticipated including the current population structure within each stream as a factor in our occupancy model. However, we failed to elicit how population structure would change over time so there were no parameter estimates for a multi-state dynamic occupancy model, only a single state dynamic occupancy model. Therefore, when using the elicited values from 2016 to construct a model for this current SSA we constructed a relatively simple presence/absence future condition model. Also, in addition to the risk assessments, we also elicited from the expert panel the probabilities that the nonnative communities will change in the future and the probabilities that streams extirpated in the future will be recolonized as a function of the connectivity to other occupied streams.

Converting elicited results to statistical distributions

Estimating the statistical distributions for the parameters from the mean and standard deviation of the “most likely” values from the elicitation would not be a measure of temporal variability in the system but would be a measure of variability among experts. This is akin to sampling variance among studies (e.g., Link and Nichols 1994, entire) and not a measure of variability of a system over space and time. Instead, we used linear extrapolation to standardize expert judgments to 90% credible intervals (CI) and assumed that best guesses represented the experts’ median values (Adams-Hosking et al. 2016, p. 251; Hemming et al. 2017, p. 176). Individual expert judgments for the median, upper, and lower 90% CI were then averaged to provide aggregated quantiles (Hemming et al. 2017, p. 177). To use the aggregated quantiles in a projection model, we fit probability distributions to the standardized judgments by assuming an appropriate family of distributions for the judgments (e.g., Beta or Gamma) and minimizing the sum of squared differences between elicited and fitted probabilities along the cumulative distribution function using the SHELF package in R (Oakley 2019, entire). The distributions, once converted from elicited data, were converted from 10-year rates to annual rates by reframing judgments in terms of probability of persistence (i.e., 1 – extirpation risk) and taking the 10^{th} root to annualize the decadal data and distribution (Gidwani and Russell, 2020, pp. 1158–1160).

To convert judgments on the effect of flood frequency to a statistical distribution, we first standardized and aggregated the judgments for each elicited time step (i.e., 2, 4, 6, 8, 10, and 12 years) as described above. We next used linear regression to determine the average effect based on the median, upper, and lower 90% CIs for each time step. The mean regression slopes for each quantile were then used to fit a gamma distribution for the effect of flood frequency as described above.

Incorporating stressor effects into the model

Flood effects

We modeled beneficial late winter/spring floods as annual stochastic events using a binomially distributed Bernoulli trial function. We determined the baseline annual probability of a beneficial late winter/spring flood (Brouder 2001, entire) occurring using stream-specific historical flow information. Using the annual mean daily discharge of the stream (where discharge is defined as the volume of water that passes a given location within a given time period) over the past 30 years, we analyzed data from 23 USGS stream gages on chub streams within the lower basin. We counted the number of years within that period that the gage registered a 'beneficial flood.' We defined a beneficial flood as a high flow event of at least ten times the average annual discharge for that stream gage occurring between January 1 and May 31 based upon Brouder's (2001) research indicating that floods within this period are beneficial to recruitment of age 1 roundtail chub. If any of the maximum mean daily discharge numbers within that period exceeded 10x average annual discharge, we identified that water year as having a beneficial flood. The results were a range of annual beneficial flood probabilities at these gages from 7% to 67% with a mean of 40%. We assigned these probabilities to stream segments at or near these gages. For streams not in proximity to a stream gage, we used the average probability of 40%. Using these probabilities, the model would determine and track in each year in each stream if a late winter/spring flood occurred. The time since the last late winter/spring flood was used in a curvilinear function to calculate the reduction in persistence probability due to flood interval ($F_{i,t}$, from equation 3) as follows:

$$F_{i,t} = 1 - \sqrt[10]{\left(1 - (b_F * Yc)\right)} \quad (4)$$

Where, Y_C is the years since the last flood, and b_F is a gamma distributed random variable with shape parameters derived from the expert elicited data ($b_F \sim gamma(10.75, 2215.60)$ using the methods described above. Gamma-distributed random variables are continuous variables bound by zero and infinity, and we used the gamma distribution here because of its flexibility and fit to the expert elicited data. We took the 10th root of the $b_F * Yc$ term in the curvilinear function to convert the 10-year elicited effect into single-year effects. The resulting randomized distribution of calculated $F_{i,t}$ values represents a variable, but increasingly negative effect of time since flood on persistence probability (Figure F-2).

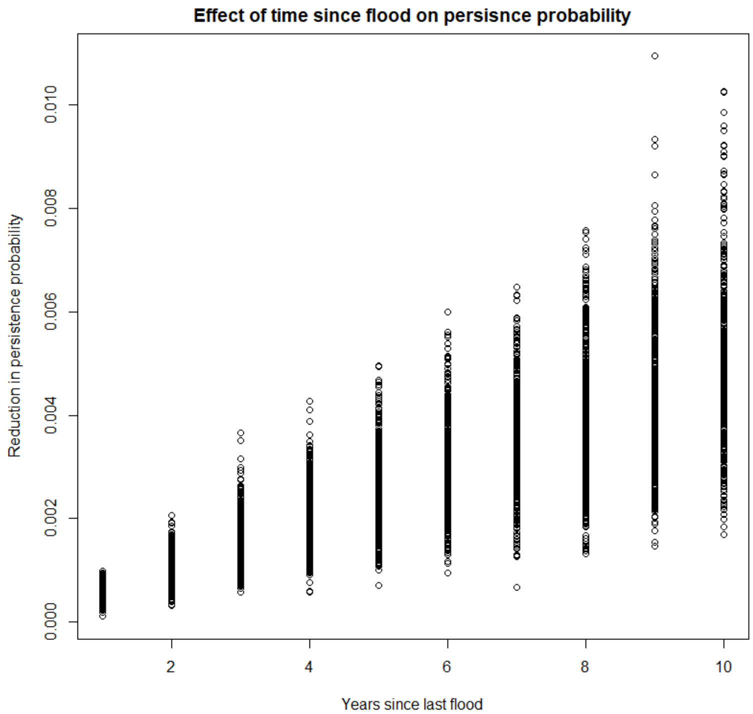


Figure F-2: The calculated annualized reduction in persistence probability ($F_{i,t}$) for 5000 simulated values of time since the last late winter/spring flood in a stream. The calculated values follow a curvilinear function where the *b* term is a gamma distributed random variable estimated from expert elicited data.

Stream length effects

Occupied stream length data were taken from the 3-species Range-wide Geospatial Database (Database) for each stream occupied by roundtail chub (see Appendix D). We used the measured stream length ($\overline{L_i}$) as a mean stream size and allowed streams to vary in length annually by up to 30% based on historical decadal streamflow variability in this range within the Gila River basin (Gutzler 2013, p. 22). The resulting function of annual stream-length variability is as follows:

$$L_{i,t} \sim normal(\overline{L_i}, 0.3 * \overline{L_i}), \qquad (5)$$

That is, stream size each year was drawn from a normal distribution with the mean set as the measured stream length for that stream and the standard deviation was set at 0.30 times the mean. This modeled variability accounted for potential annual variation in the stream size, and annual variation in the area occupied as well as uncertainty/error in the estimates of occupied stream length.

Experts believed that the size of a stream had an influence on the probability of persistence, as in, smaller streams had less habitat diversity, fewer spawning sites, less food, thus populations at these sites had lower probability of persistence. The expert elicitation did not include chub populations formerly classified as *G. intermedia,* which typically occupy smaller streams with less habitat diversity and greater isolation, thus the elicited values may be biased toward greater reductions in persistence probability for smaller streams than if all of the chub populations been considered. We elicited the effect of stream size on persistence probability during the elicitation workshop (see details above). We elicited the probable reduction in persistence probability for streams of different sizes, then used the results and variability within and among experts to estimate the expected variability in the relationship. With those results we fit a curvilinear relationship wherein the effect decreases as stream length decreased as follows:

$$S_{i,t} = 1 - \sqrt[10]{\left(1 - \left(b_{s,t} * e^{(x_{s,t} * L_{i,t})}\right)\right)/100}, \quad (6)$$

Where, $b_{i,t}$ and $x_{i,t}$, are normally distributed random variables based on the variability measure among experts. The resulting relationship exhibits some variability around a relationship that declines sharply between stream length of 0.5 km and approximately 15 km and reaches effectively zero effect after approximately 30 km (Figure F-3).

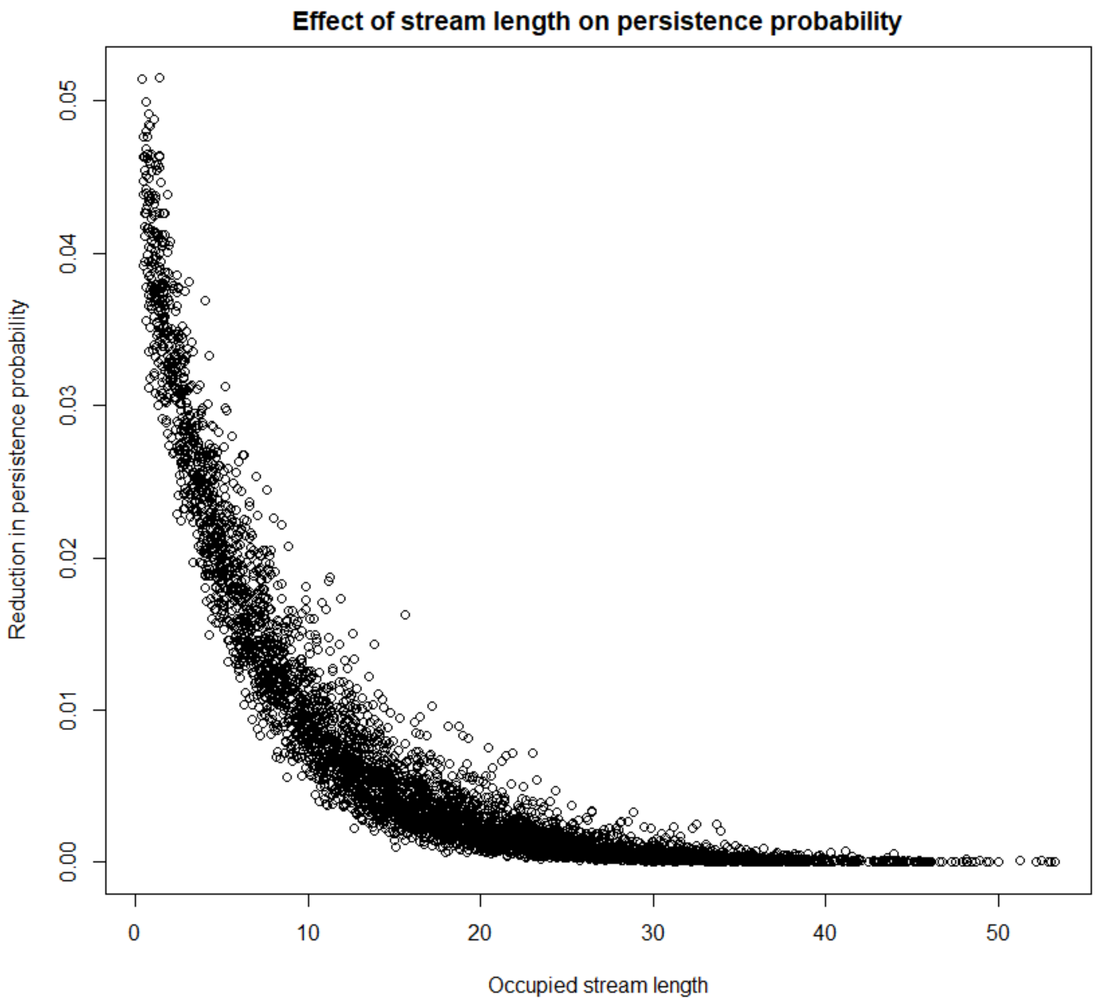


Figure F-3: 5000 simulated stream lengths and calculated stream length reduced annual persistence probabilities, based on the estimated relationship elicited from experts with regression parameters modeled as normally distributed random variables

Nonnative community

Nonnative community classifications were established in terms of their probable effect on chub populations. Full details on this classification system are available in the current conditions section of the species status assessment document and described in Appendix D. Briefly, nonnative communities that had predatory species that affect all life stages of chubs were classified as level three (C = 3), communities that had other predators that affect only one life stage of chub as well as other species of chub competitors were classified as level 2 (C = 2), and communities that had only space and food resource competitors were considered level 1 (C = 1). Sites without any exotic species were classified as level 0 (C = 0). Initial classifications of each known chub population were assigned using data collected by the states and managed in the Database. The nonnative community at each stream was modeled as a stochastic variable that can change over time ($C_{i,t}$) from one classification to another. The future category of the nonnative community was dependent on the current category and the transition probabilities elicited from species experts (see Appendix E). We asked experts to estimate the probability of each classification transition was ($T_{i,t}^{C_{i,t},C_{i,t+1}}$ e.g., $C_{i,t}$ = 3-> $C_{i,t+1}$ = 2, $C_{i,t}$ = 3 -> $C_{i,t+1}$ = 1, etc.) over a ten-year period. For this question, we did not elicit a range of responses for each transition but only a most likely (see Appendix E). We took the 10th root of the elicited rates to convert to annual rate, and we applied a blanket temporal variability in annual rate of 0.2 times the mean elicited rate (i.e., $S.D. = 0.2 * \sqrt[10]{T_i^{C_{i,t},C_{i,t+1}}}$). This allowed some parametric variance in spite of the lack of elicited variation within experts and 0.2 times the mean equates to a 20% co-efficient of variation which is commonly used in simulation modeling to incorporate unmeasured variability (e.g., Kremer 1983 p. 196; Sweka et al. 2007, p. 280; McGowan et al. 2011, p. 1403; Wildhaber et al. 2017, p. 15). In the model, these transition rates are generated as sets of four independent normally distributed random variables for each of the starting categories to transition to each of the other possible categories or staying the same (e.g., 0->0, 0->1, 0->2, 0->3). The 4 random variables are then normalized to add to 1.0. We used a series of if statements to determine the current nonnative community category and to set the appropriate transition probabilities. Then we used the rcat function in the "Laplacesdeamon" package in R (R core development team 2019, Statisticat 2021) to generate random exotic community category transitions through each time step (Figure F-4).

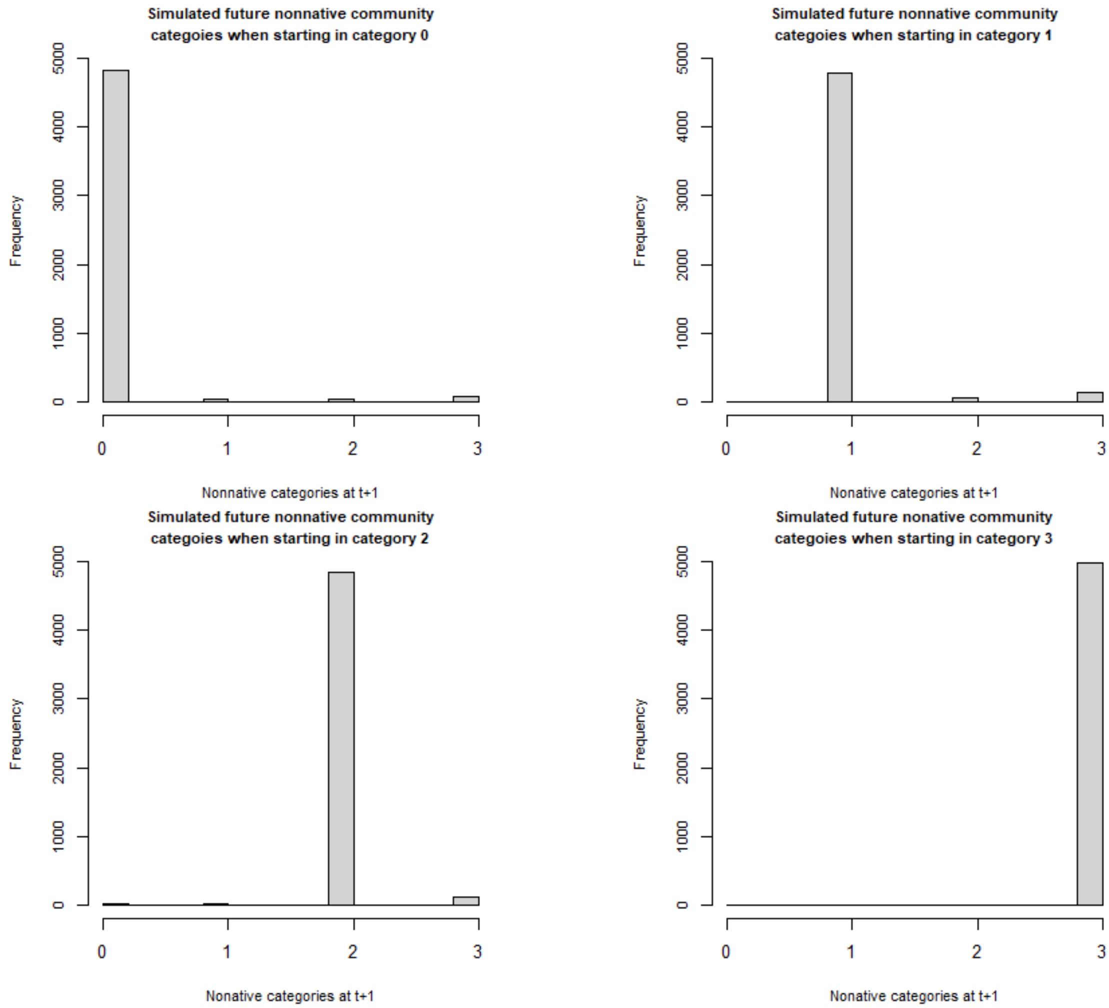


Figure F-4: Simulated nonnative community categories if the initial category was 0 (top left), 1 (top right), 2 (bottom left), or 3 (bottom right) based on the expert elicited transition probabilities among categories.

The effect that the nonnative community had on persistence probability was modeled similarly to the stream length and flood interval, as a factor subtracted from natural persistence probability (eq 1). The $E_{i,t}$ persistence probability penalty depended on the category of the exotic community in that stream in that year. We used if statements to determine the current exotic community category and then use beta distributed random variables to apply the persistence probability for each stream in each year. The beta distribution was different for each level of the exotic community (Figure F-5) with exotic community level 0 having no effect on persistence probability, level 1 the smallest effect (median = 0.006, C.I. = (0.002, 0.016), level 2 larger (median = 0.017, C.I. = (0.009, 0.036), and level 3 the highest (median = 0.047, C.I. = (0.014, 0.133), with increasing variability and uncertainty as the community level increases.

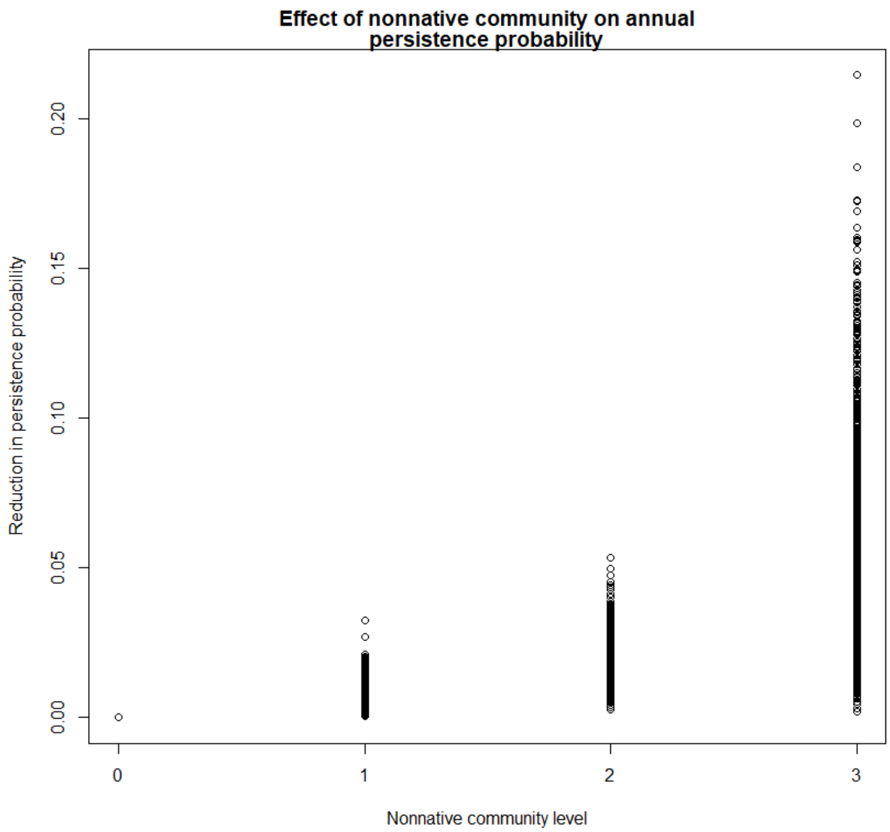


Figure F-5: Simulated exotic community annualized effects on persistence probability using a 5000 sample of exotic community classes and the corresponding beta distributed randomized penalty draws.

Recolonization

Our model incorporated a function to allow for recolonization of a site if the stream becomes extirpated during the simulation. For natural recolonization, a stream needs to be "connected" to at least one occupied stream in order to have a source for natural recolonization. Experts thought that recolonization probability ($P_{r,i,t}$) would increase as the number of connections to occupied streams increased. We elicited the probability of recolonization with different number of connections from experts (see Appendix E) and developed a curvilinear function to mathematically capture the relationship:

$$P_{r,i,t} = \left(\left(\frac{(MinR - MaxR)}{\left(1 + \left(\left(\frac{N_{C,i,t}}{I_{R,i,t}}\right)^{S_{R,i,t}}\right)\right)} \right) + MaxR \right) \Big/ 100, \quad (7)$$

Where *MinR* and *MaxR* are the minimum (0) and maximum (100) possible values of $P_{r,i,t}$, $N_{C,i,t}$ is the number of streams that stream i is connected to in year t, and $I_{Ri,t}$, and $S_{Ri,t}$, are regression parameters that are modeled as uniformly distributed random variables. $I_{Ri,t}$ varies uniformly between 4.56 and 15.15, and

$S_{Ri,t}$ varies between 0.54 and 1.86. The equation is divided by 100 to rescale the elicited values (which were elicited as percentages) to be between 0 and 1 for modeling as a probability in the simulation. The function calculates the probability of recolonization as a function of number of connections but with wide stochastic variation (Figure F-6). We then used the $P_{r,i,t}$ values in a randomized binomially distributed Bernoulli trial for each extinct stream in each year to determine if the stream is recolonized.

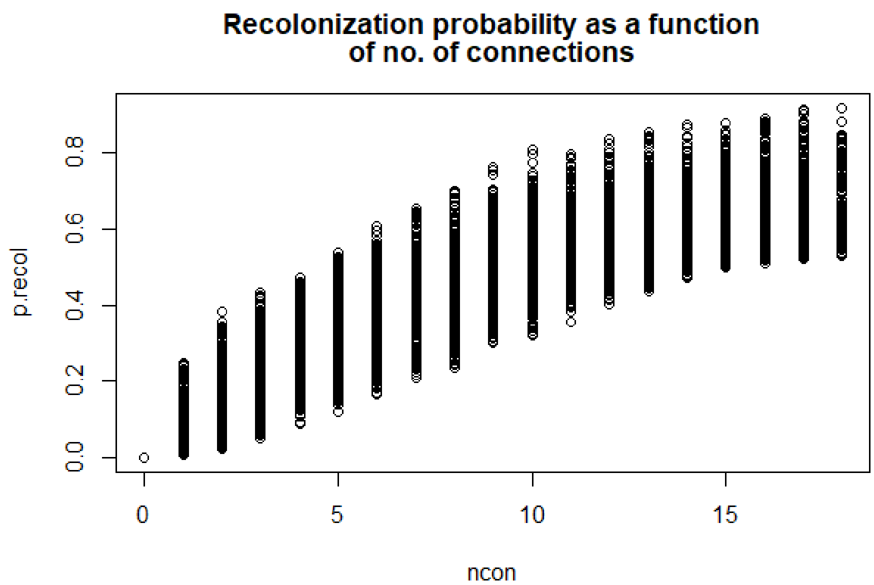


Figure F-6: Simulated probability of recolonization ("p.recol") for 5000 values of number of connections ("ncon") demonstrating the curvilinear form and the expected variability around the expert elicited values.

The number of sites that each site was connected to was based on site-specific data. We evaluated each stream segment and determined its connectivity by spatially identifying which stream segments it was physically connected to. We determined that fish could not move upstream through constructed barriers or some types of severe natural barriers (e.g., waterfalls) but could move down stream through most barriers; thus, upstream sites tended to have fewer connections than downstream sites.

Modeling alternative future scenarios

We ran the model under different scenarios to account for potential changes in future environmental conditions. These scenarios were related to simulating the effects of ongoing climate change and accounted for potential enhanced management efforts in the future. We ran four scenarios (Scenarios 1-4) to provide a range of future extirpation probabilities for each of the chub streams.

On-going management actions

The elicitation of probabilities for extinction penalty posed by each threat and the nonnative community transition probabilities were elicited in the absence of management in the system. Experts were asked to look over the known history of population dynamics, their own experience, and their own knowledge base to determine their responses to the elicitation questions about the likelihood of future events and their effects on roundtail chubs. However, in recent decades the state and Federal wildlife management agencies have increased management and protections for chub, including the construction of fish passage barriers to limit the spread of nonnative species and eradication efforts to reduce the effects of nonnatives in places where they are present. These ongoing management efforts likely reduce/alter the elicited values. Observed extirpation events since 1971 have been at least an order of magnitude less frequent than experts indicated in their elicitation responses. This summary information was not evaluated at the time of elicitation in 2016. We identified the number of stream segments (using similar methodologies to define stream segments for currently occupied streams) that have been extirpated for any reason over the last 50 years (see SSA report Appendix D for a list of all extirpated streams) and divided that number of the total number of stream segments (see Table F--6 for a summary of how these figures were calculated). This resulted in roundtail chub extirpations of about 2% of stream segments per decade from any cause. These results of actual stream extirpations during recent times are approximately an order of magnitude less than the risks derived from the 2016 elicitation of experts (based on preliminary model runs under scenario 1, as described below). With that in mind we used the model to predict future status in the absence of management using the expert elicited values (scenario 1) and then designed scenarios that reduced the persistence probability penalties caused by each factor by an order of magnitude as follows (scenarios 2-4):

$$P_{R,i,t} = P_{N,t} - \left({E_{i,t}}/{10}\right) - \left({F_{i,t}}/{10}\right) - \left({S_{i,t}}/{10}\right). \qquad (8)$$

As part of these scenarios, the nonnative community transition probabilities were adjusted so that the probability of nonnative communities getting worse (e.g., $T_t^{1,2}$ or $T_t^{2,3}$) were reduced by an order of magnitude (i.e., divided by 10) and the remaining transition probability was added to the probabilities of remaining in the same nonnative community state. The probability of the nonnative community improving (e.g., $T_t^{3,2}$) were left at the expert elicited values. For example, the mean values for the transition probabilities for category 2 were $T_t^{2,0} = 0.05$, $T_t^{2,1} = 0.05$, $T_t^{2,2} = 0.7$ and $T_t^{3,2} = 0.2$ in the "absence of management scenario", and the mean values were set to $T_t^{2,0} = 0.05$, $T_t^{2,1} = 0.05$, $T_t^{2,2} = 0.88$ and $T_t^{3,2} = 0.02$ in scenario 2, the "with management scenario" (Figure F-7).

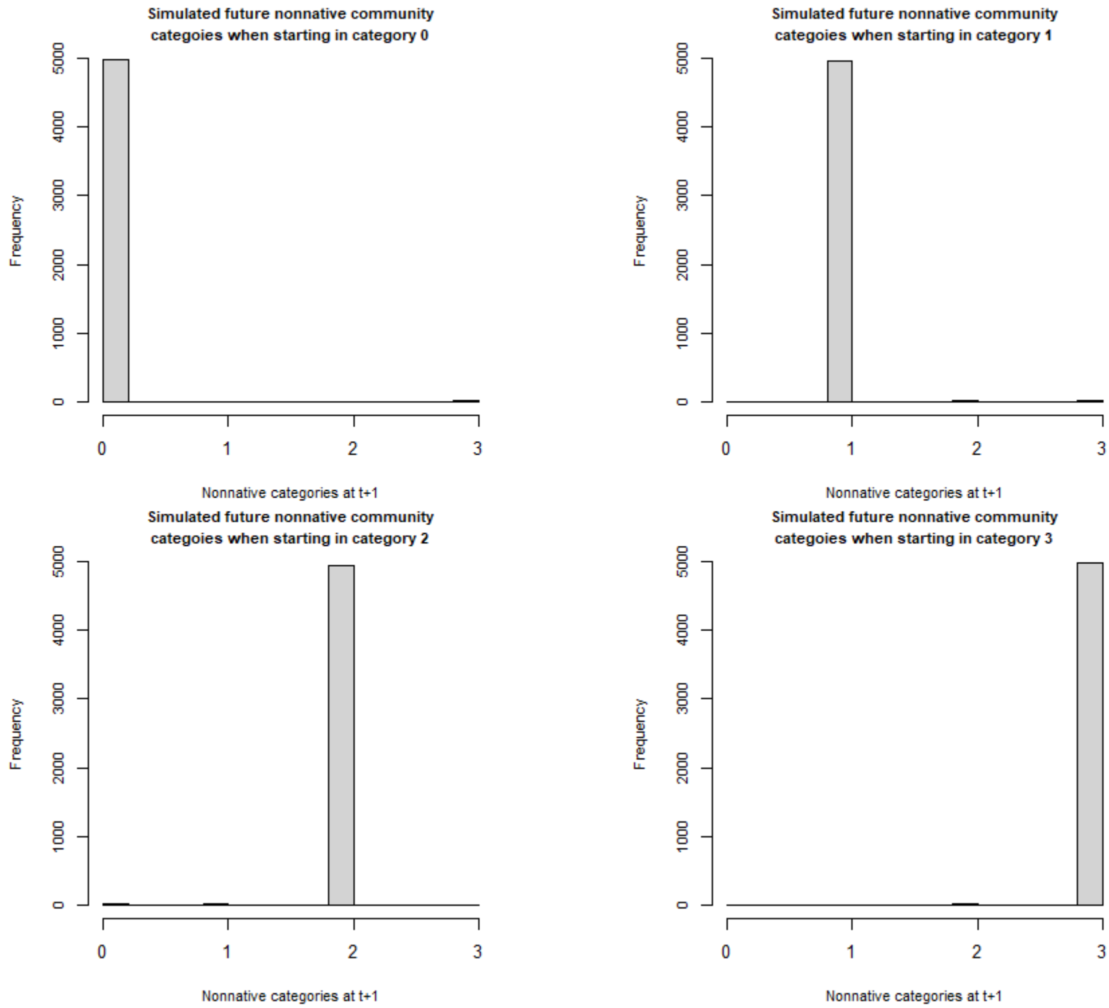


Figure F-7: Simulated exotic community category transitions if the initial category was (A) 0, (B) 1, (C) 2, or (D) 3 based on the adjusted expert elicited transition probabilities among categories to account for on-going management.

These adjusted parameter values were the core rates for the "ongoing management scenario" (scenario 2), the "on-going management with climate change scenario" (scenario 3), and the "on-going management with climate change and additional conservation" (scenario 4).

Climate change effects

We modeled climate change effects in two scenarios by assuming a decreasing stream length over time and a reduced flood frequency. We used a declining stream length as a surrogate for loss of habitat that could occur from future drying due to climatic conditions. As stream lengths decline (i.e., habitat decreases) the risk of extirpation increases. As a measure of these effects, we used as a surrogate from published projections of average stream flow decline. Gutzler (2013, p. 21) projected median annual flow decreases in the upper Gila River of 8% for the period 2021-2050. Das et al. (2011, p. 3) projected a decrease in annual flow of 13.3% across the Colorado River basin. For our projections of climate effects, we assumed a 10.7% (average of 8 and 13%) decrease in the mean stream length of all the streams over the 30-year time frame we ran the model (see Timeframe below). We recognize that these projected large-scale changes in streamflow do not equate to changes in individual stream lengths. However, these projections provide a reasonable benchmark for plausible relative changes upon which we can use to make inferences regarding changes to the amount of habitat within roundtail chub streams in the future. We annualized the rate of stream length loss by dividing the 30-year loss by thirty to get an annual rate, 0.357% each year. The model retained annual variation in stream size, but it also includes a function to reduce the mean stream size each year under scenarios 3 and 4 as follows:

$$L_{i,t} \sim normal(\overline{L_i}, 0.2 * \overline{L_i}) \times (1 - SLD_t),$$

Where *SLD* is the stream length decline in that year, modeled as percent/100. In year 1 SDL was 0.00357, in year 5 it was 0.0143, in year 10 it was 0.0321 and in year 30 it was 0.107.

We also accounted for the potential changes in the flood frequency resulting from future climate change. The climate change literature in the region is inconclusive regarding the frequency of spring floods and persistence of streamflow (Seager et al. 2013, p 482; Jaeger et al. p. 4; Robles et al. 2021, p. 21). However, the potential for increased floods is much greater in the Upper Colorado Basin and Sierra Nevada due to projected increases of rain on snow events; models show less of an effect in Arizona and New Mexico from overall reductions in winter snowpack due to warmer winters (Musselman et al. 2018, pp. 809–810). However, rainfall intensity could increase in a warmer climate, which may shift the flooding period to early winter (Musselman et al. 2018, p. 310). We do not know what effect shifting the flood season by three months may have on chub spawning cues and/or recruitment of age 1 fish. Given that uncertainty, we applied a function that explored the consequences of less frequent floods during the late winter/spring to demonstrate how the worst possible predicted effects of climate change might affect chub populations. Therefore, for scenarios including future climate change we reduced the annual chance of late winter/spring floods by 25% for all streams as an estimate for extreme climate change effects. For example, streams that had an annual 40% chance of a beneficial flood, we reduced that to 30%. We chose this rate of change as a reasonable estimate based on the variability that has been observed in recent decades at stream flow gages within the chub's range. The model simply multiplied the measured mean flood frequency by 1 – (% reduction/100). There was no temporal direction to the effect (i.e., floods did not become less frequent as time progresses). We focused our attention to late winter/spring floods because we have research to indicate these are important floods for recruitment of age 1 chub (Brouder 2001, p. 307). Floods that occur at other times of year may still result in chub recruitment, but we assume for this modeling effort that late winter/spring floods may be most beneficial to successful recruitment.

Enhanced conservation management actions:

For two scenarios (Scenarios 2 and 3) we accounted for ongoing management through the adjustment of the effects of several model parameters. We reevaluated the magnitude of the risks, which were elicited based on all historical changes and in the absence of management efforts, in context with the empirical data on losses of chubs from stream segments more recently over the last 50 years. This summary information had not been available at the time of elicitation. We identified the number of stream segments (using similar methodologies to define stream segments) that have been extirpated for any reason over the last 50 years and divided that number of the total number of stream segments. This resulted in chub extirpations of about 2% of stream segments per decade from any cause. These results of actual stream extirpations during recent times are approximately an order of magnitude less than the risks derived from the 2016 elicitation of experts. As stated in the model description section, to assess the chub status using empirical data, we reduced the risks from the elicited values by one order of magnitude.

To evaluate the possible benefits of additional conservation and management of the system we incorporated functions to adjust the spread of nonnative species among the sites and to increase the recolonization probability to mimic restocking efforts that management agencies might take if a site goes extinct. For the "ongoing management + climate + additional conservation" scenario (Scenario 4) we adjusted the nonnative state transition parameters and the recolonization probabilities to simulate increases in management efforts in the future. We considered the conservation efforts since 2004 where, on average, about 0.76 PMUs per year (see Table 4.2 in conservation actions section) have had nonnatives removed represents the ongoing conservation efforts. To estimate enhanced management efforts, we increased the average values of improving nonnative transitions by 50% so that streams with high effect nonnative communities have a higher chance or improvement due to conservation management efforts (Figure F-8).

For the nonnative transition parameters, we incorporated the capacity to increase the probability of the nonnative community to transition from higher (i.e., more nonnative species) to lower classifications (e.g., transitioning form category 2 to category 1)

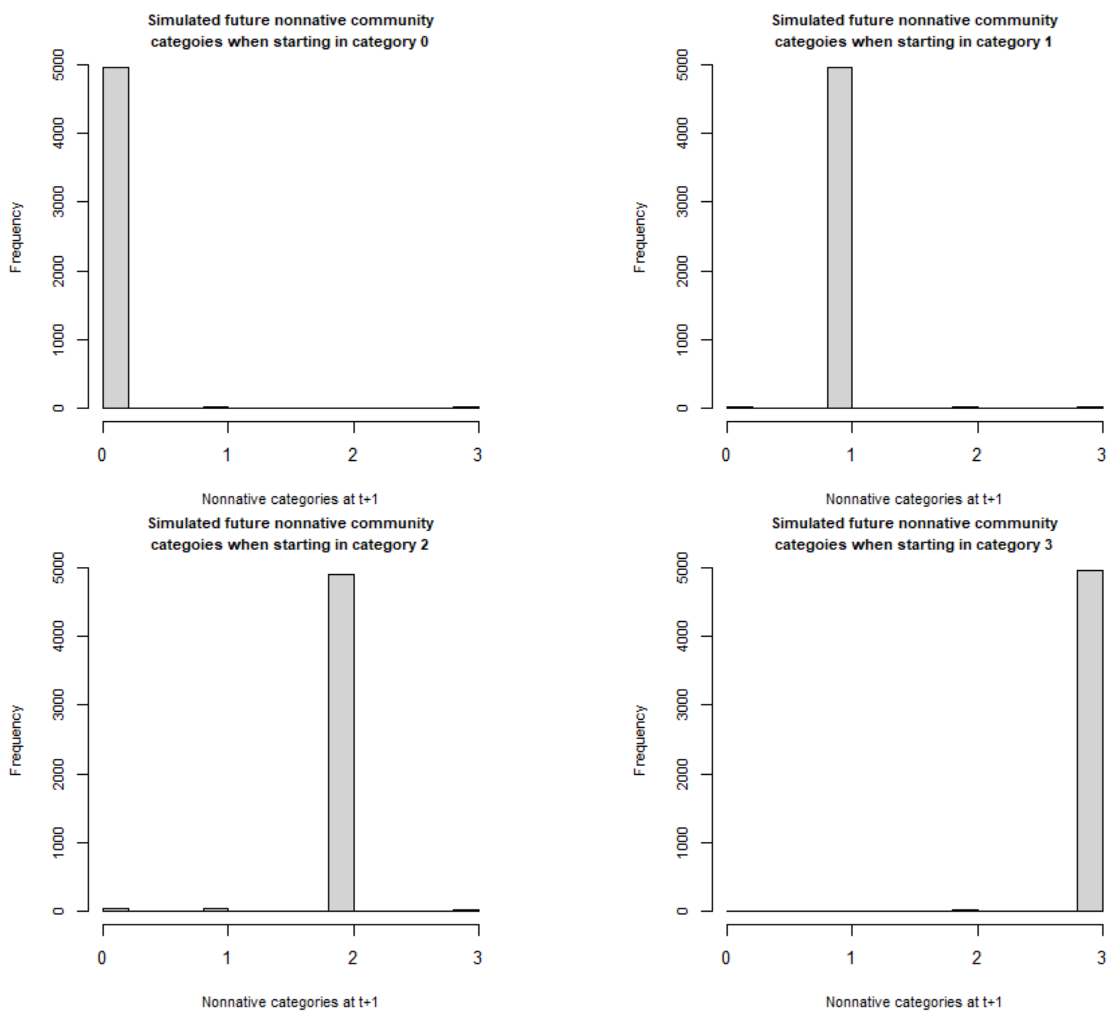


Figure F-8: Simulated nonnative community category transitions if the initial category was (A) 0, (B) 1, (C) 2, or (D) 3 based on the adjusted expert elicited transition probabilities among categories to account for on-going management with enhanced management to contain or reduce the spread of nonnative species.

Timeframe

We chose to run the model for 50 years into the future. This timeframe likely represents about 6-8 generations for roundtail chub (assuming generation time is the average age of reproducing adults, and that average adult ages are in the 6 to 8-year range). We have high uncertainty about the relationship between future climate change and the expected variation in the parameters of our model (specifically changes in stream length and flood frequency), as these are not confidently projected in climate models, and the future trends in precipitation in the southwest is particularly difficult to project due to uncertainty around modeling summer monsoonal rain (Fassnacht 2006, p. 2196). In addition, projecting ongoing management into the future beyond 50 years increases our uncertainty significantly.

Scenarios

A summary of the four scenarios is shown in Table F-1.

Table F-1: Summary of assumptions future scenarios in roundtail chub occupancy model. Scenario1 used risk estimates as elicited from experts. Scenarios 2-4 used reduced risk values.

	SCENARIOS			
Factors	**1. No Mgt & Low Climate Change Effects**	**2. Ongoing Mgt & Low Climate Change Effects**	**3. Ongoing Mgt & High Climate Change Effects**	**4. Enhanced Mgt & High Climate Change Effects**
Management	No Management Efforts	Ongoing Management Efforts	Ongoing Management Efforts	Enhanced Management Efforts
Nonnatives	*Spread as assessed.*	*Reduced spread.*	*Reduced spread.*	*Reduced spread. Increased nonnative removals.*
Recolonization	*Recolonization as assessed.*	*Recolonization as assessed.*	*Recolonization as assessed.*	*Recolonization as assessed. Increased management stocking.*
Climate Change	No additional climate effects.	No additional climate effects.	Increased climate effects.	Increased climate effects.
Stream Length	*Stream length as assessed.*	*Stream length as assessed.*	*Decreased stream lengths.*	*Decreased stream lengths.*
Flood Frequency	*Beneficial flood frequency as assessed.*	*Beneficial flood frequency as assessed.*	*Decreased flood frequency.*	*Decreased flood frequency.*

Scenario 1 is the baseline model run that uses the full elicitation risk estimates with no adjustments for ongoing or enhanced management or additional risks for future climate.

Scenario 2 includes reduced risk estimates with no adjustments for enhanced management or additional risks for future climate change.

Scenario 3 includes reduced risk estimates and increases in risks associated with future climate change and no adjustments for enhanced management.

Scenario 4 includes reduced risk estimates and increases in risks associated with future climate change and reduced rate of exotic transitions and increase probabilities of recolonization to mimic enhanced management.

Results

Our model predicted that the number of extant streams across the range are expected to decline in all scenarios, but the severity of decline was much greater for scenario 1, the expert elicited values in the absence of management. Starting with 159 occupied streams, under scenario 1 there were a median of 62 streams remaining occupied at 30 years and 48 at 50 years (Table F-2). The other three scenarios exhibited similar patterns of less severe decline with approximately 133 to 140 sites remaining occupied at 30 years and 125 to 138 streams occupied range-wide at 50 years (Table F-2, Figure F-9). Regardless of the scenario, one site in the Verde River analysis unit, always went extinct in the first year of the simulation because it is a stocked pond and the recorded stream length is 0km, which incurs a very small persistence probability. A second site in the Verde River system is fairly short (<5km) with a non-native community of level 3 and no connections, and that site almost always went extinct in the first few years of the simulation. Climate effects modeled in scenarios 3 and 4 had minimal effect on future status, however, post hoc additional simulations showed that much larger decreases in stream size (e.g., 10% decrease annually) much lower flood frequencies (e.g., 90% less frequent floods) would results in fewer streams being occupied in 30-50 years. Those effects of climate change are far greater than we expect based on literature review, but the patterns indicate that the model functions work properly. Further conservation effort by decreasing the spread of exotics and increasing restocking rates after site extinction (Scenario 4) exhibited some capacity to counter act possible system stressors on chub populations. Despite increased management effort in scenario 4, the number of sites occupied over time never increases above the initial because we did not model currently unoccupied sites that could become occupied though stocking or natural colonization. We did not include in the model an opportunity for the expansion of streams occupied beyond the initial number. This effectively underestimates the potential for management effects and overestimates the potential total number of extirpations because management agencies have in recent past expanded the number of streams occupied by chubs through stocking. We also used the model to output the proportion of replicates for each stream segment that remained extant at 30 years and 50 years for each scenario (Table F-5, Supplementary Material. These results were used to project the probability of persistence for stream kilometers of habitat by watershed in the future (see main text of the SSA report for these results).

Table F-2: Median number of streams remaining occupied, 2.5 percentile (lower bound) and 97.5 percentile (upper bound) at 30 years and 50 years for all 4 scenarios. The model was initiated with 159 streams.

	30 years			50 years		
	median	lower bound	upper bound	median	lower bound	upper bound
Scenario 1	62	50	73	48	34	64
Scenario 2	133	123	139	126	113	133
Scenario 3	133	125	141	125	116	134
Scenario 4	140	133	145	138	131	142

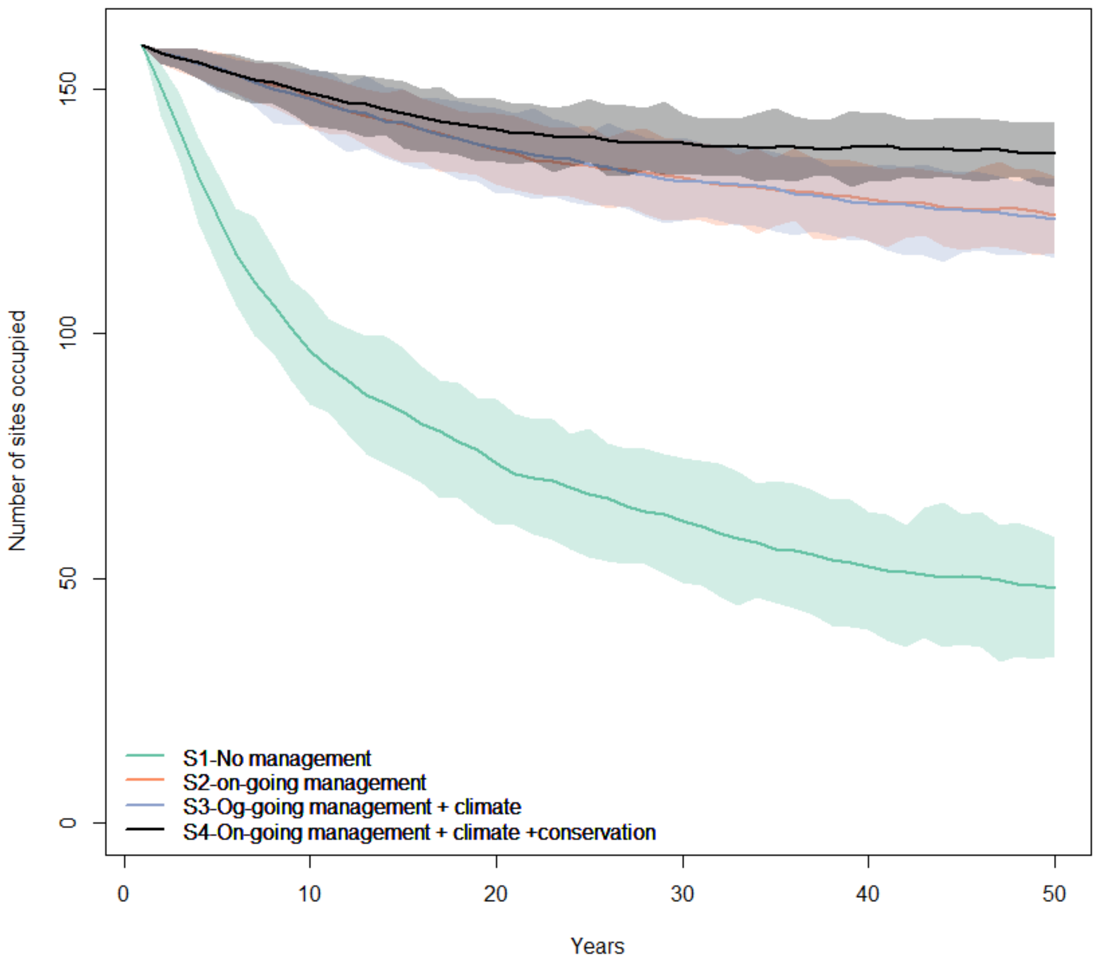


Figure F-9: Number of stream sites projected as occupied over 50 years for 4 different future condition scenarios.

We designated the streams into HUC06 watershed analysis units. Each HUC06 serves as a representation unit for considering future status of the roundtail chub. The number of streams extant in each analysis unit varied among future conditions scenarios. Under scenario 1, six out of seven HUC06 declined by >50% in the first 30 years and the 7th HUC06 declined by 45% (Table F-3). The other scenarios exhibited less severe declines (Table F-3, Figure F-10) with each HUC06 declining between 3-25% in the first 30 years of the simulation. The Upper Gila River exhibited some stability in scenario 1 with 51.6% still extant at 50 years, but the other HUCs lost between 70 and 90 % of sites. The other three scenarios had 67-95% site remaining occupied in each HUC06 at 50 years.

Table F-3: Median number of streams occupied (and the lower (LB) and upper bound (UB) of the 95% confidence interval) under each of the four future scenarios for each of the seven representation units (HUC06 watersheds).

		Initial	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	HUC06		Median	LB	UB	Median	LB	UB	Median	LB	UB	Median	LB	UB
Year 30	Bill Williams River	29	12.88	6.72	18.53	25.66	22.72	28.00	25.43	22.00	28.00	26.27	23.00	29.00
	Upper Gila River	29	10.21	3.00	16.00	23.99	19.72	27.00	24.04	20.00	27.53	25.05	22.00	27.53
	San Pedro-Wilcox	16	3.88	0.00	6.52	12.72	9.72	15.00	12.73	9.72	15.00	13.49	10.00	15.00
	Santa Cruz River	12	2.91	0.00	6.00	10.77	9.00	12.00	10.74	9.00	12.00	11.74	11.00	12.00
	Salt River	26	7.65	1.72	14.00	19.36	15.00	22.53	19.60	16.00	23.00	20.57	18.00	23.00
	Verde River	39	21.00	17.00	25.53	32.66	29.00	36.00	32.77	29.00	36.00	34.36	31.00	36.53
	Lower Gila-Aqua Fria	8	3.48	0.00	6.00	7.30	5.72	8.00	7.39	6.00	8.00	7.78	7.00	8.00
Year 50	Bill Williams River	29	8.62	0.00	17.00	24.65	20.00	28.00	24.90	21.72	28.00	25.99	23.72	28.00
	Upper Gila River	29	8.33	0.72	13.53	23.06	18.00	27.00	23.01	18.72	26.00	24.49	20.72	28.00
	San Pedro-Wilcox	16	2.37	0.00	6.00	11.62	7.00	14.53	11.33	8.00	14.00	13.46	10.72	15.00
	Santa Cruz River	12	0.85	0.00	3.00	9.79	7.72	12.00	9.64	7.72	12.00	11.51	10.00	12.00
	Salt River	26	5.44	0.00	10.00	17.74	14.00	21.53	17.76	14.00	21.53	20.29	17.00	24.00
	Verde River	39	20.05	15.72	24.53	30.90	28.00	34.00	31.03	26.72	35.00	34.10	31.00	36.00
	Lower Gila-Aqua Fria	8	2.54	0.00	5.00	7.08	5.00	8.00	7.00	5.00	8.00	7.70	6.00	8.00

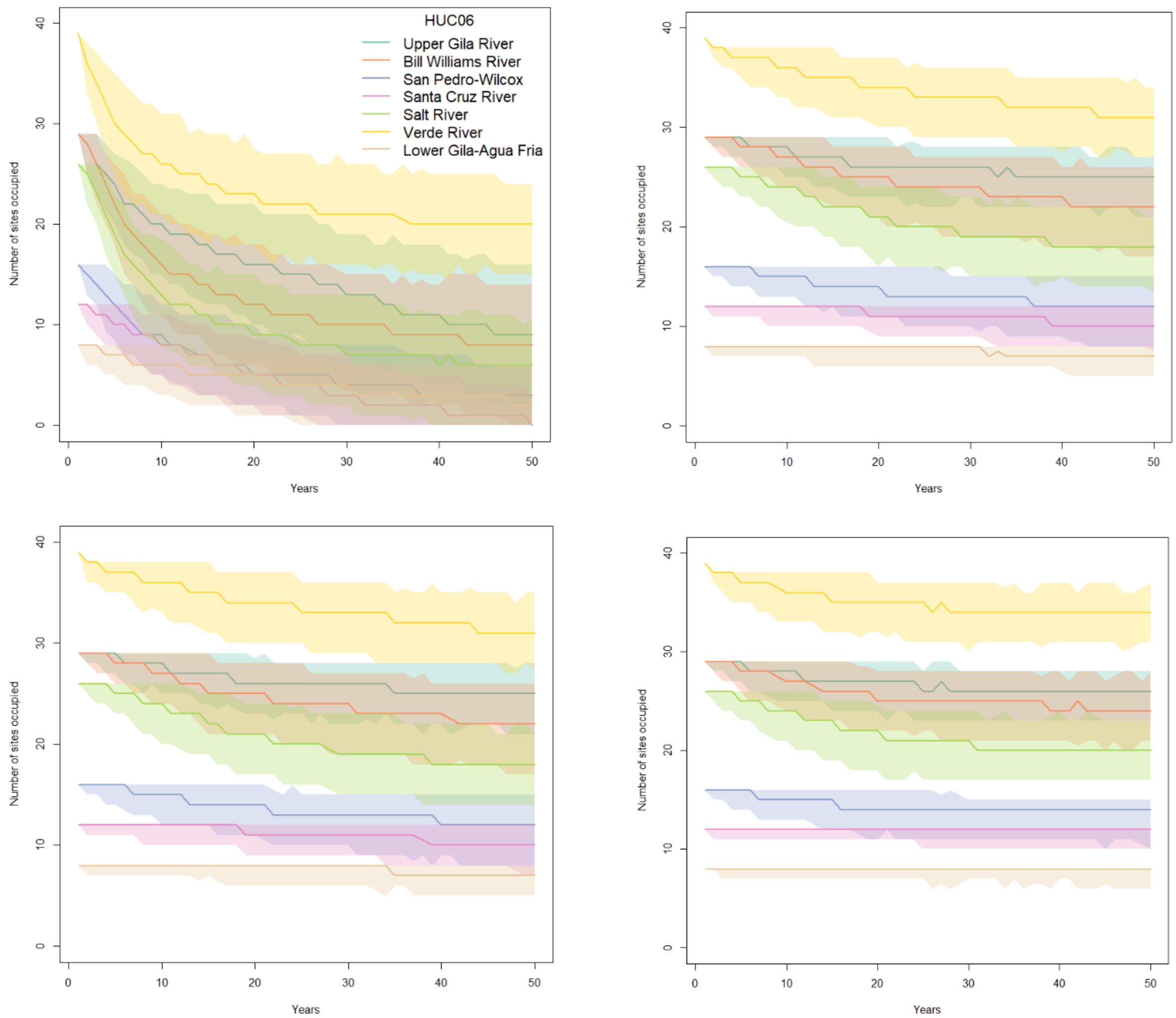


Figure F-10: Median number of stream sites occupied under each of the 4 future conditions scenarios, broken out by representation unit (HUC06 watershed designation) with 95% confidence intervals.

Sensitivity Analysis

We also ran a sensitivity analysis for model outputs using a regression type sensitivity analysis (e.g., Wisdom and Mills 1997, pp. 307–309; McGowan et al. 2017, pp. 124–127). The sensitivity used the management and climate change functions described above to randomize the input values for the management factors or climate factors which directly change the parameter values for the nonnative community transitions, the change in stream length over time, the flood frequency and the recolonization probability. In the regression sensitivity analysis, the response variable was the proportion of sites extant at 30 years and the independent variables four variable factors. We used random uniform distributions to generate 100 varied input for each of the 4 factors that affect persistence probability: nonnative category transition rates, change in flood frequency, change in stream length, and recolonization probability. These values were allowed to vary above and below the current assessed levels and the level simulated in the specific scenarios, to explore wide variation and the effects of future status.

With these varied inputs and simulated outputs, we estimated the effect of each factor on the proportion of streams that went extinct in 30 years using a binomial generalized linear regression model. The regression coefficient parameters can tell us the direction of the effect (i.e., positive, negative, or neutral) the strength of the effect and the relative importance of each input variable. The resulting regression model was:

$$Pextant = 1.56640 + (0.717 \times Precent\ change\ in\ nonnative\ transition\ rate) + (-0.192 \times Percent\ change\ in\ flood\ frequency) + (-0.036 \times Percent\ change\ in\ steam\ length) + (0.277 \times recolnization\ probability),$$

The regression parameters for percent change in flood frequency and percent change in stream length were not "statistically significantly" different from zero (Table F-4), meaning their estimated effect on future proportion of sites occupied was small. Whereas the regression coefficients for "percent change in nonnative transition rate" and the recolonization probabilities were significantly positive. As the nonnative transition rate improved (i.e., 3->2, 2->1, etc. transitions), the number of sites still extant at 30 years increased, and similarly as the recolonization rate increased, the number of sites still extant at 30 years increased (Figure F-11). The recolonization effect was stronger than nonnative transition.

Table F-4: Regression coefficients for the sensitivity analysis regression model linking the proportion of sites extant at 30 with change in nonnative transitions, flood frequency, stream length and recolonization probability.

Regression parameter	mean (S.D.)	p-value
Intercept	1.56 (0.764)	0.040
Percent change in nonnative transitions	0.717 (0.075)	<2e-16
Percent change in flood frequency	-0.19248 (0.137)	0.159
Percent change in stream length	-0.036 (0.736)	0.961
Recolonization probability	0.277 (0.121)	0.022

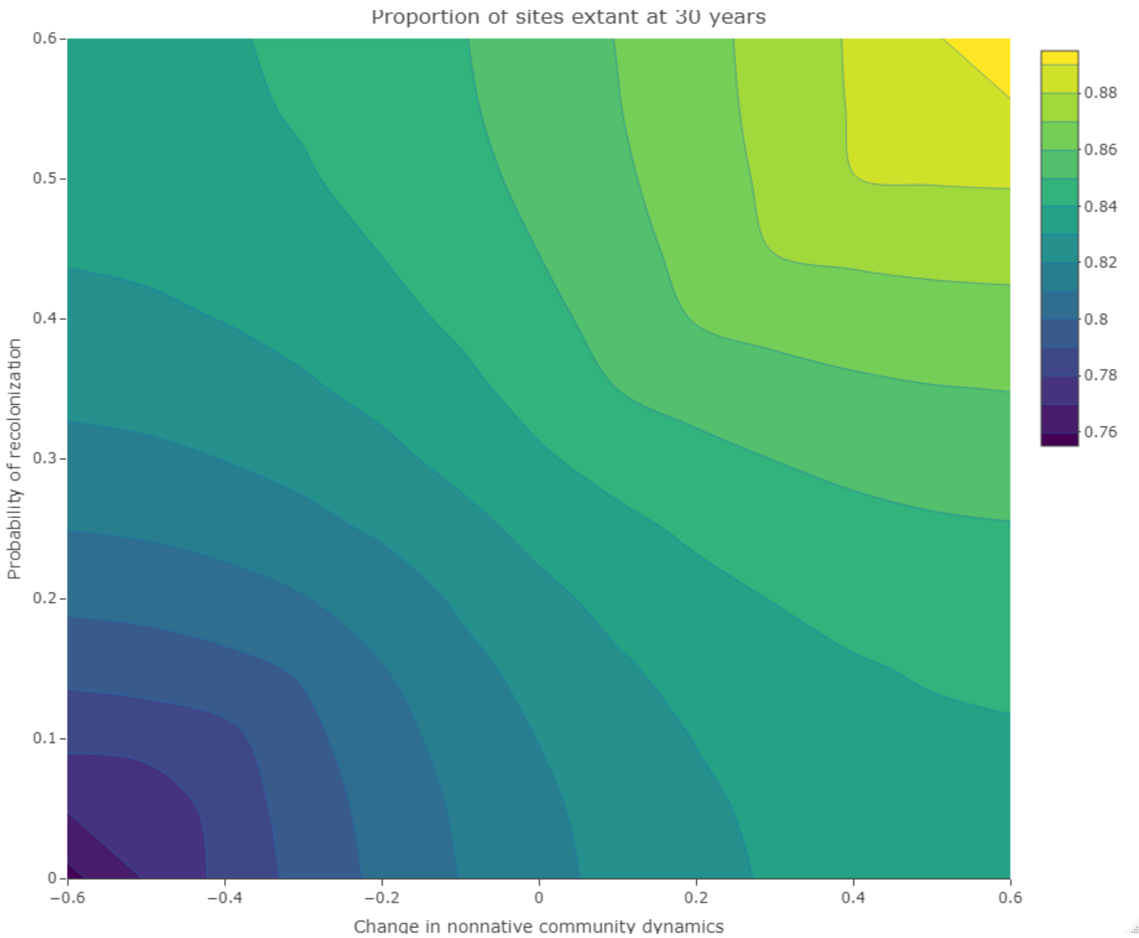


Figure F-11: Contour surface depicting the expected proportion of sites occupied 30 years into the future as the probability of recolonization increases and the percent change in nonnative transition rates increases.

These sensitivity analyses can give insight into the relative importance of each model component (i.e., the four primary factors affecting persistence probability) to the future status of the populations and species. The x-axis ranges from -0.6 to 0.6 which are the proportional change in exotic transition probabilities. For example, -0.5 means that transitions from bad categories to good categories (e.g., 3->2) are 50% less likely and transitions from good categories to bad categories (e.g., 2->3) are 50% more likely. Similarly, an x-axis value of 0.25, means there was a 25% increase in the bad condition to good condition and a corresponding decrease in good condition to bad condition transition rates. In simpler terms, the x-axis values are the percent increase (positive values) or decrease (negative values) in the in the likelihood that nonnative community categories improve over the community transition values in scenario 2. These are not direct changes in the transition rates but rather paired increase for some transition and decrease for others because we used the management scenario modeling framework to introduce the sensitivity variation into the simulations. On the one hand, it is inefficient for describing the sensitivity analysis and results, but on the other hand we used the existing model functions to implement the sensitivity regression analysis. Figure F-11 shows how the total proportion of sites extant at 30 years changes as the nonnative transition rates and the recolonization rates change.

A regression model with change in nonnative community transition rates, that is % deviation from the values simulated in scenario 2, as the only predictor of number of sites occupied 30 years in the future shows a strong positive trend (Figure F-12). These results tell us that if our modeled rate of nonnative community transitions were over or underestimated by up to 60% the expected number of sites occupied would vary between ~110 and ~135.

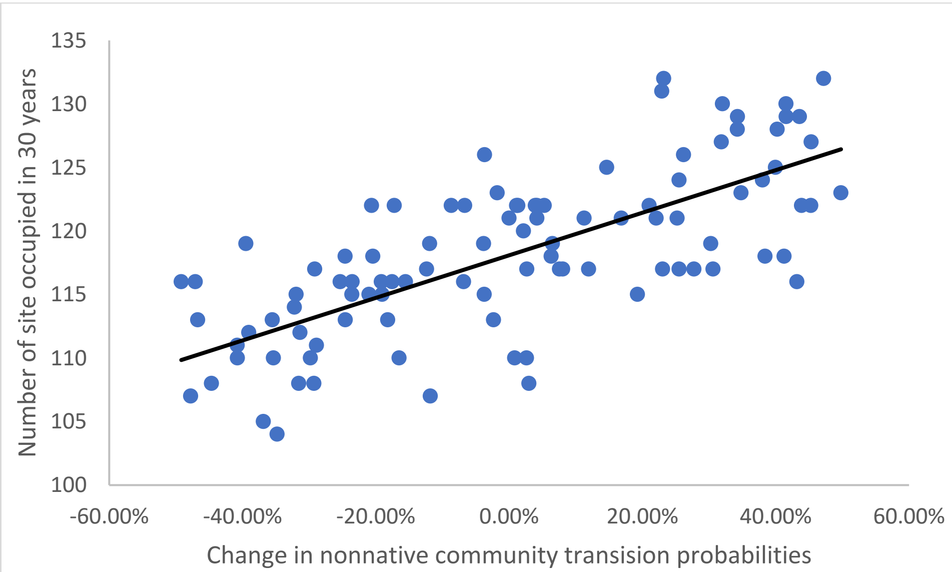


Figure F-12: Relationship of the expected number of sites occupied in 30 years (y-axis) with the percent change in in the high to low nonnative community transitions. 0% on the x-axis is the expert elicited values with ongoing management applied to the model in scenario two, positive values indicate an increase in the transition from high categories to low and negative values indicate an increase in the transition from low categories to high.

Model Limitations and caveats

Our model is limited largely by a lack of data to support the parameterization of the non-native species effects on chub persistence probability and several of the other parameters. Expert elicitation is a common and accepted approach for parameter estimation when data are lacking, and we went to great lengths to incorporate uncertainty and test output sensitivity through varied scenarios and regression analyses. Our model is also highly dependent on the current state of the system as the starting point of the simulations. More generalized models would incorporate more uncertainty into the starting conditions and perhaps not model specific stream segments, but rather generate a set of virtual populations based on current conditions but dissociated from specifics to then predict general patterns in future state rather than the future state of each specific stream. However, state and federal biologist have put significant effort in to monitoring these populations over decades, and it was important to incorporate that knowledge and data to the extent it was available.

Literature cited

All references are available in Appendix I of the Roundtail Chub SSA Report.

Supplementary Material:

Table F-5: Calculated probability of persistence for each stream segment (PMU) modeled for roundtail chub. The values represent the proportion of iterations out of 500 when each stream segment was persisting at 30 and 50-year time steps under each scenario. 'cd' is the reference code for PMUs from the state database, or as assigned. Stream length is the length of each segment, in km. Values are reported at 30 years and 50 years in the future under each of the four evaluated scenarios (Sc 1 is Scenario 1, etc.).

			Scenarios at 30 years				Scenarios at 50 years			
Stream_Name	**cd**	**Stream Length**	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**
Bill Williams River Watershed, HUC06: 150302										
Gonzales Wash	cd0380	*3.3*	0.64	1	0.99	1	0.5	0.99	1	0.98
McGee Wash	cd0381	*3.3*	0.61	0.99	0.99	1	0.4	0.97	0.97	0.99
Ash Creek	cd0506	*5.1*	0.39	0.86	0.85	0.84	0.38	0.9	0.86	0.95
Cow Creek	cd0507	*7.2*	0.68	0.98	0.99	1	0.43	0.99	0.97	0.98
Fork Rock Creek	cd0513	*2.4*	0.57	0.94	0.98	0.97	0.43	0.93	0.96	1
Trout Creek	cd0514	*54.6*	0.44	0.83	0.91	0.77	0.38	0.93	0.92	0.88
East Ash Creek	cd0429	*2.7*	0.25	0.95	0.9	0.97	0.06	0.89	0.88	0.96
Ash Creek	cd0430	*4.4*	0.18	0.95	0.92	0.98	0.07	0.89	0.93	0.96
Burro Creek	cd0378	*8.0*	0.32	0.95	0.91	0.98	0.12	0.88	0.9	0.99
Pine Creek	cd0504	*4.0*	0.28	0.93	0.91	0.98	0.09	0.93	0.85	1
Francis Creek	cd0375	*4.4*	0.5	0.96	0.91	0.97	0.51	0.81	0.9	0.9
Conger Creek	cd0376	*1.1*	0.54	0.85	0.88	0.92	0.47	0.89	0.87	0.95
Conger Creek	cd0377	*9.6*	0.69	1	1	1	0.5	0.99	0.98	1
Burro Creek	cd0379	*67.5*	0.59	0.87	0.86	0.91	0.47	0.93	0.91	0.87
Boulder Creek	cd0502	*10.4*	0.57	0.88	0.86	0.89	0.45	0.88	0.94	0.9
Wilder Creek	cd0414	*14.2*	0.53	0.99	0.97	1	0.21	0.98	0.97	0.99
Stone Corral Canyon	cd0415	*4.3*	0.53	0.94	0.97	1	0.22	0.94	0.96	0.98
Boulder Creek	cd0425	*10.9*	0.33	0.91	0.91	0.96	0.14	0.92	0.91	0.92
Boulder Creek	cd0499	*0.9*	0	0.65	0.66	0.9	0	0.37	0.33	0.84
Boulder Creek	cd0496	*4.4*	0.34	0.95	0.95	0.96	0.16	0.88	0.93	0.95
Francis Creek	cd0374	*10.1*	0.64	1	1	1	0.56	0.98	0.95	1
Cottonwood Wash	cd0500	*1.8*	0	0.06	0.08	0.05	0	0	0	0.05
Cottonwood Wash	cd0501	*6.8*	0.22	0.75	0.83	0.77	0.11	0.69	0.73	0.78
Smith Canyon	cd0503	*8.6*	0.44	0.98	0.98	0.97	0.17	0.95	0.92	0.97
Sycamore Creek	cd0505	*20.1*	0.26	0.82	0.73	0.76	0.15	0.8	0.77	0.84
Kirkland Creek	cd0508	*12.5*	0.27	0.79	0.76	0.83	0.09	0.83	0.78	0.77
Santa Maria River	cd0515	*38.3*	0.22	0.78	0.82	0.75	0.18	0.79	0.76	0.8
Fork Rock Creek	cd0512	*0.8*	0.62	0.97	0.99	0.99	0.52	0.98	0.98	0.98
Fork Rock Creek	cd0510	*0.5*	0.61	0.97	1	1	0.45	0.98	0.98	0.98

Stream_Name	cd	Stream Length	Scenarios at 30 years				Scenarios at 50 years			
			Sc 1	**Sc 2**	**Sc 3**	**Sc 4**	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**
Upper Gila River Watershed, HUC06: 150400										
Mule Creek	cd0306	*5.1*	0.65	0.82	0.87	0.83	0.41	0.90	0.84	0.87
Sycamore Canyon	cd0269	*1.5*	0.10	0.76	0.82	0.97	0.00	0.56	0.65	0.94
Turkey Creek	cd0273	*9.5*	0.07	0.82	0.86	0.93	0.00	0.56	0.68	0.90
Blue River	cd0282	*18.6*	0.59	1.00	0.97	1.00	0.35	0.96	0.98	0.95
Blue River	cd0354	*27.5*	0.33	0.89	0.91	0.93	0.34	0.82	0.90	0.95
Blue River	cd0355	*5.2*	0.43	0.82	0.84	0.91	0.33	0.85	0.90	0.93
Dix Creek	cd0266	*6.0*	0.64	1.00	0.99	0.99	0.59	1.00	0.95	0.99
Right Prong Dix Creek	cd0271	*0.9*	0.67	0.99	0.99	0.96	0.54	0.97	0.98	0.96
Harden Cienega Creek	cd0249	*1.2*	0.55	0.83	0.82	0.91	0.54	0.85	0.81	0.83
Harden Cienega Creek	cd0251	*2.3*	0.56	0.86	0.87	0.86	0.50	0.83	0.91	0.82
Bonita Creek	cd0318	*15.1*	0.03	0.81	0.83	0.90	0.00	0.60	0.67	0.98
Bonita Creek	cd0321	*4.3*	0.05	0.87	0.77	0.90	0.00	0.66	0.68	0.97
Middle Fork Gila River	cd0243	*24.4*	0.46	0.86	0.88	0.90	0.36	0.87	0.82	0.86
Middle Fork Gila River	cd0248	*36.4*	0.42	0.86	0.91	0.90	0.37	0.89	0.82	0.85
West Fork Gila River	cd0257	*29.9*	0.62	0.87	0.89	0.96	0.50	0.94	0.93	0.93
East Fork Gila River	cd0285	*45.2*	0.49	0.86	0.78	0.90	0.43	0.88	0.89	0.85
Black Canyon Creek	cd0286	*3.6*	0.52	0.92	0.94	0.96	0.47	0.96	0.93	0.94
West Fork Gila River	cd0291	*3.9*	0.46	0.82	0.87	0.88	0.45	0.85	0.84	0.85
West Fork Gila River	cd0300	*4.6*	0.55	0.89	0.82	0.88	0.39	0.90	0.84	0.79
Black Canyon Creek	cd0359	*1.0*	0.51	0.91	0.88	0.91	0.47	0.92	0.86	0.93
Eagle Creek	cd0297	*47.9*	0.13	0.67	0.69	0.81	0.05	0.71	0.75	0.72
Eagle Creek (East Eagle)	cd0301	*15.4*	0.14	0.87	0.87	0.96	0.04	0.79	0.84	0.89
Blue River	cd0524	*0.8*	0.51	0.79	0.88	0.85	0.40	0.87	0.90	0.89
San Carlos River	cd0988	*33.2*	0.01	0.33	0.39	0.33	0.00	0.14	0.11	0.25
Ash Creek	cd0989	*25.8*	0.01	0.39	0.33	0.30	0.00	0.19	0.08	0.26
Pigeon Creek	cd0335	*0.1*	0.43	0.95	0.94	0.96	0.27	0.96	0.96	0.97
San Francisco River	cd0326	*7.3*	0.55	0.88	0.90	0.88	0.50	0.87	0.89	0.87
Knight Canyon	cd1000	*3.1*	0.09	0.74	0.72	0.77	0.04	0.70	0.77	0.70
Middle Prong Creek	cd1001	*2.0*	0.11	0.83	0.88	0.93	0.04	0.79	0.81	0.88
San Pedro-Wilcox Watershed, HUC06:150502										
Aravaipa Creek	cd0312	*37.4*	0.00	0.11	0.07	0.07	0.00	0.03	0.00	0.08
Bass Canyon	cd0270	*2.7*	0.63	0.98	0.98	0.97	0.48	1.00	0.95	0.98
Bass Canyon	cd0277	*1.0*	0.62	0.97	0.98	0.98	0.50	0.96	0.99	0.98
Bass Canyon	cd0280	*1.0*	0.60	1.00	0.94	0.99	0.39	0.97	0.96	0.98
Double R Canyon	cd0281	*0.5*	0.59	0.96	0.95	0.99	0.41	0.97	0.97	0.98
Hot Springs Canyon	cd0288	*7.2*	0.71	0.98	0.98	0.98	0.55	0.97	0.95	0.99
Hot Springs Canyon	cd0296	*2.5*	0.58	1.00	0.98	0.99	0.49	0.93	0.98	0.99

Stream_Name	cd	Stream Length	Scenarios at 30 years				Scenarios at 50 years			
			Sc 1	Sc 2	Sc 3	Sc 4	Sc 1	Sc 2	Sc 3	Sc 4
Redfield Canyon	cd0298	*0.3*	0.05	0.79	0.81	0.71	0.00	0.73	0.80	0.82
Redfield Canyon	cd0303	*1.1*	0.10	0.81	0.74	0.78	0.00	0.78	0.80	0.82
Redfield Canyon	cd0305	*5.2*	0.09	0.84	0.79	0.81	0.01	0.78	0.78	0.69
Redfield Canyon	cd0310	*2.5*	0.08	0.75	0.70	0.79	0.00	0.81	0.74	0.79
Redfield Canyon	cd0307	*0.9*	0.08	0.84	0.84	1.00	0.00	0.71	0.69	0.96
O'Donnell Canyon	cd0309	*0.1*	0.04	0.80	0.85	0.96	0.00	0.67	0.65	0.87
O'Donnell Canyon	cd0365	*0.6*	0.01	0.54	0.63	0.93	0.00	0.26	0.33	0.82
O'Donnell Canyon	cd0366	*1.8*	0.03	0.76	0.76	0.93	0.00	0.52	0.55	0.81
O'Donnell Canyon	cd0367	*0.9*	0.06	0.74	0.72	0.78	0.00	0.66	0.69	0.74
Santa Cruz River Watershed, HUC06: 150503										
Bear Canyon	cd0254	*4.2*	0.14	0.85	0.82	0.96	0.03	0.73	0.74	0.97
Sheehy Spring	cd0265	*0.2*	0.01	0.55	0.62	0.93	0.00	0.25	0.28	0.87
Sabino Creek	cd0261	*6.1*	0.30	0.97	0.93	0.98	0.10	0.94	0.89	0.98
Sabino Creek	cd0263	*2.1*	0.10	0.86	0.85	0.99	0.02	0.71	0.77	0.96
Sabino Creek	cd0255	*0.7*	0.39	0.97	0.96	0.98	0.10	0.92	0.97	0.99
Romero Canyon	cd0252	*0.4*	0.08	0.83	0.81	0.96	0.01	0.69	0.71	0.98
Romero Canyon	cd0250	*1.1*	0.19	0.93	0.93	1.00	0.06	0.90	0.84	0.99
Romero Canyon	cd0246	*1.9*	0.29	0.95	0.97	0.98	0.08	0.88	0.94	0.96
Cienega Creek	cd0320	*4.2*	0.40	0.97	0.92	1.00	0.13	0.97	0.90	0.98
Cienega Creek	cd0348	*0.7*	0.30	0.97	0.96	0.97	0.10	0.99	0.94	0.96
Mattie Canyon	cd0373	*0.8*	0.36	0.91	0.94	0.99	0.13	0.93	0.91	1.00
Bear Canyon	cd0259	*1.9*	0.40	0.96	0.96	0.98	0.11	0.95	0.95	0.99
Salt River Watershed, HUC06: 150601										
Rock Creek	cd0274	*0.4*	0.57	1.00	0.97	1.00	0.52	0.96	0.99	0.98
Haigler Creek	cd0283	*13.1*	0.48	0.83	0.84	0.92	0.45	0.87	0.91	0.85
Tonto Creek	cd0313	*25.8*	0.51	0.87	0.82	0.85	0.50	0.86	0.89	0.88
Gordon Canyon Creek	cd0316	*6.4*	0.57	0.93	0.95	0.97	0.44	0.90	0.95	0.96
Spring Creek (and Dinner Creek)	cd0325	*31.7*	0.54	0.86	0.91	0.84	0.42	0.83	0.90	0.86
Rock Creek	cd0329	*13.6*	0.51	0.86	0.82	0.85	0.45	0.85	0.81	0.91
Buzzard Roost Canyon	cd0331	*1.7*	0.44	0.86	0.94	0.89	0.49	0.84	0.90	0.83
Marsh Creek	cd0346	*10.5*	0.41	0.89	0.92	0.88	0.41	0.87	0.86	0.83
Beaver Creek	cd0253	*14.8*	0.19	0.81	0.76	0.89	0.08	0.81	0.85	0.96
Boneyard Creek (and N. Fork E. Fork Black River)	cd0264	*13.5*	0.22	0.85	0.85	0.91	0.05	0.80	0.87	0.97
East Fork Black River	cd0268	*12.7*	0.17	0.88	0.84	0.93	0.11	0.77	0.78	0.92
Black River (and W. Fork Black River)	cd0272	*23.1*	0.17	0.68	0.74	0.78	0.08	0.69	0.81	0.70
Gun Creek	cd0304	*0.6*	0.52	0.88	0.88	0.91	0.43	0.84	0.91	0.87

Stream_Name	cd	Stream Length	Scenarios at 30 years				Scenarios at 50 years			
			Sc 1	Sc 2	Sc 3	Sc 4	Sc 1	Sc 2	Sc 3	Sc 4
Tonto Creek	cd0317	*8.9*	0.48	0.90	0.89	0.84	0.53	0.85	0.83	0.85
Cherry Creek	cd0289	*3.6*	0.00	0.05	0.07	0.12	0.00	0.00	0.00	0.10
Salt River	cd0267	*1.4*	0.13	0.55	0.56	0.59	0.01	0.39	0.46	0.64
Ash Creek	cd0276	*5.1*	0.23	0.83	0.87	0.99	0.04	0.61	0.77	0.97
Salt River	cd0368	*21.9*	0.01	0.27	0.19	0.22	0.00	0.06	0.11	0.17
Canyon Creek	cd0990	*71.6*	0.40	0.96	0.92	0.99	0.17	0.89	0.85	0.97
Cibeque Creek (below barrier)	cd0991	*2.6*	0.09	0.85	0.84	0.99	0.02	0.71	0.72	0.99
Carrizo Creek	cd0992	*81.3*	0.01	0.23	0.32	0.40	0.01	0.11	0.10	0.20
Corduroy Creek	cd0993	*42.0*	0.00	0.27	0.27	0.33	0.00	0.08	0.10	0.23
East Fork White River	cd0994	*16.9*	0.45	0.98	0.96	0.98	0.21	0.95	0.94	0.99
North Fork White River	cd0995	*24.0*	0.38	0.99	0.97	0.99	0.19	0.96	0.91	1.00
White River	cd0996	*29.1*	0.23	0.71	0.62	0.70	0.17	0.74	0.75	0.69
West Fork Black River	cd0290	*1.2*	0.00	0.38	0.51	0.93	0.00	0.11	0.14	0.89
Verde River Watershed, HUC06:150602										
Verde River	cd0247	*14.1*	0.64	0.93	0.86	0.87	0.72	0.95	0.92	0.95
Verde River	cd0262	*23.3*	0.76	0.95	0.92	0.94	0.76	0.92	0.95	0.93
Webber Creek	cd0279	*1.5*	0.86	0.96	0.99	0.99	0.82	0.97	0.96	0.97
Verde River	cd0284	*23.0*	0.70	0.95	0.91	0.92	0.75	0.88	0.92	0.92
Verde River	cd0287	*77.2*	0.77	0.90	0.95	0.93	0.72	0.94	0.94	0.91
Verde River	cd0299	*27.4*	0.68	0.94	0.92	0.92	0.75	0.92	0.96	0.91
West Clear Creek	cd0302	*29.4*	0.77	0.89	0.86	0.92	0.70	0.93	0.93	0.94
East Verde River	cd0311	*16.5*	0.68	0.91	0.90	0.94	0.74	0.89	0.92	0.93
Wet Bottom Creek	cd0332	*5.7*	0.83	0.90	0.95	0.92	0.70	0.95	0.91	0.92
Rock Creek	cd0333	*1.8*	0.72	0.93	0.95	0.94	0.71	0.88	0.94	0.89
The Gorge	cd0334	*1.6*	0.74	0.92	0.89	0.92	0.80	0.91	0.91	0.90
Fossil Creek	cd0339	*7.3*	0.70	0.90	0.92	0.95	0.73	0.93	0.90	0.90
Pine Creek	cd0343	*13.5*	0.79	0.90	0.92	0.95	0.73	0.91	0.94	0.93
Oak Creek	cd0350	*63.6*	0.74	0.89	0.93	0.85	0.82	0.83	0.90	0.92
Canyon Creek	cd0352	*2.6*	0.69	0.93	0.91	0.95	0.76	0.89	0.90	0.97
Sycamore Creek	cd0353	*6.9*	0.71	0.95	0.94	0.88	0.74	0.89	0.92	0.90
East Verde River	cd0360	*50.3*	0.73	0.89	0.91	0.89	0.79	0.90	0.94	0.95
Verde River	cd0364	*38.8*	0.72	0.88	0.94	0.90	0.74	0.93	0.94	0.89
East Verde River	cd0997	*5.6*	0.76	0.93	0.94	0.97	0.75	0.93	0.91	0.91
Verde River	cd0999	*17.4*	0.78	0.89	0.94	0.91	0.69	0.94	0.93	0.92
Spring Creek	cd0256	*4.9*	0.00	0.07	0.09	0.12	0.00	0.00	0.00	0.11
Fossil Creek	cd0344	*5.2*	0.18	0.90	0.91	0.97	0.04	0.79	0.83	0.95
Fossil Creek	cd0345	*3.7*	0.24	0.95	0.97	0.96	0.08	0.91	0.95	0.98
Fossil Creek	cd0342	*2.0*	0.22	0.96	0.97	0.99	0.14	0.94	0.92	0.98

Stream_Name	cd	Stream Length	Scenarios at 30 years				Scenarios at 50 years			
			Sc 1	Sc 2	Sc 3	Sc 4	Sc 1	Sc 2	Sc 3	Sc 4
Fossil Creek	cd0341	*9.5*	0.50	0.99	0.97	1.00	0.14	0.98	0.98	1.00
West Clear Creek	cd0315	*30.2*	0.03	0.66	0.70	0.94	0.00	0.53	0.48	0.95
Willow Valley	cd0322	*5.6*	0.01	0.64	0.68	0.94	0.00	0.46	0.48	0.93
Walker Creek	cd0292	*3.5*	0.81	0.98	0.99	0.98	0.73	0.99	1.00	0.98
Wet Beaver Creek	cd0275	*3.9*	0.76	0.93	0.94	0.93	0.75	0.90	0.91	0.93
Roundtree Canyon	cd0358	*4.0*	0.72	1.00	0.99	1.00	0.80	1.00	0.97	1.00
Verde River	cd0362	*39.9*	0.00	0.23	0.26	0.26	0.00	0.07	0.09	0.17
Williamson Valley Wash	cd0260	*0.7*	0.00	0.57	0.71	0.92	0.00	0.21	0.31	0.83
Red Tank Draw	cd0323	*2.6*	0.71	0.88	0.92	0.94	0.71	0.96	0.92	0.87
Gap Creek	cd0370	*0.4*	0.83	0.99	0.99	0.99	0.74	0.98	0.98	0.99
Gap Creek	cd0361	*1.8*	0.22	0.94	0.93	0.97	0.07	0.89	0.87	0.95
Gap Creek	cd0369	*0.9*	0.13	0.84	0.80	0.97	0.03	0.70	0.66	0.96
LO Pocket Tank	cd0356	*0.0*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rarick Canyon	cd0319	*3.4*	0.02	0.57	0.69	0.91	0.00	0.31	0.39	0.91
Verde River	cd0998	*2.5*	0.72	0.92	0.91	0.94	0.63	0.86	0.87	0.93
Lower Gila-Agua Fria Watershed, HUC06: 150701										
Larry Creek	cd0293	*0.5*	0.08	0.88	0.80	0.98	0.02	0.74	0.66	0.96
Lousy Canyon	cd0357	*0.5*	0.08	0.81	0.86	0.96	0.00	0.72	0.76	0.93
Silver Creek	cd0336	*2.1*	0.49	0.95	0.97	0.92	0.37	0.93	0.92	0.93
Indian Creek	cd0278	*3.8*	0.56	0.99	0.97	1.00	0.45	0.95	0.99	0.98
Indian Creek	cd0295	*8.0*	0.67	0.99	0.99	0.99	0.39	0.99	0.99	0.98
Little Sycamore Creek	cd0314	*1.4*	0.60	0.97	0.94	0.97	0.35	0.99	0.95	0.99
Sycamore Creek	cd0324	*0.3*	0.40	0.92	0.93	0.97	0.37	0.88	0.91	0.94
Sycamore Creek	cd0327	*5.5*	0.53	0.94	0.96	0.97	0.41	0.93	0.87	0.94

Table F-6: Calculation of proportion of PMUs extirpated on average per decade since 1971. Top table is a list of streams and their length that have been estimated since 1971. Bottom table shows the calculation to arrive at an estimated 2% loss of streams per decade (10% overall) since 1971.

Stream Name (PMU)	Number of PMUs	Stream KM	Comment
Cave Creek	1	35.31	No Barriers
Seven Springs Wash	1	2.09	No Barriers
Dry Beaver Creek	1	19.43	No Barriers
Rye Creek	1	2.16	No Barriers
T4 Springs	1	0.54	
Turkey Creek	1	20.59	No Barriers
Post Canyon	1	5.36	No Barriers
Santa Cruz River 1	3	17.48	No known barriers, PMU splits at international boundaries.
Santa Cruz River 2		65.32	
Santa Cruz River 3		140.7	
Tularosa River	1	57.62	No known barriers
Upper Gila River 1	6	155.52	PMU splits at Fort Thomas Diversion, Curtis Canal Diversion, San Jose Diversion, AZ/NM state line, and Sunset Diversion.
Upper Gila River 2		15.89	
Upper Gila River 3		98.17	
Upper Gila River 4		34.83	
Upper Gila River 5		8.11	
Upper Gila River 6		95.85	
Totals	**17** **PMUs**	**631.9** **Length**	Total estimated extirpated PMUS and their total stream length since 1971.

Calculation	PMUs	KM	Comments
Extant streams	159	1845.0	Current number of extant PMUs and total stream length occupied
Total extirpated + extant	176	2476.9	Estimated occupied stream and km in 1971
Proportion extirpated (=17/176)	**9.7%**	**25.5%**	**Proportion of streams (PMUs) and stream lengths extirpated since 1971**
Average PMUs extirpated per decade (=17/10)	3.4		
Average Proportion of extirpated per decade (=3.4/174)	**1.9%**	**This is the estimate of overall average proportion of lost PMUs (stream segments) by decade from all sources.**	

APPENDIX G: EXPERT ELICITATION FOR ROUNDTAIL CHUB MODEL

Purpose & Background

As part of the status review for the roundtail chub (Lower Colorado River DPS) and headwater chub, in 2016 we, the U.S. Fish and Wildlife Service (FWS), held an expert elicitation workshop to help inform a planned model for the species status assessment for the two fishes. At that time we considered *Gila robusta*, *Gila nigra, and Gila intermedia*, separate taxa. Following our review of new taxonomic information from the Joint American Fisheries Society-American Society of Ichthyology and Herpetology Committee on Names of Fishes, in 2017, the FWS determined that the former three species should be considered one species, roundtail chub (*G. robusta*) (82 FR 16981). As a result, the previous status review was suspended until we renewed the review in 2021. As part of the latest status review of the roundtail chub (Lower Colorado River Basin), which includes all populations of the former headwater chub and Gila chub, and updated species status assessments (SSAs), we used the results of the 2016 elicitation in our model for the species. While we conducted the elicitation separately for the two previously recognized species (roundtail and headwater chubs), and we report them separately here, the elicitation results were very similar and were combined for the recent roundtail chub modeling effort in support of the roundtail chub SSA (see Appendix F).

Expert Elicitation Process

The use of expert opinion to inform decision-making in the face of uncertainty is a long-standing practice (*e.g.*, Martin *et al.* 2005, MacMillan and Marshall 2006). If conducted rigorously, information obtained from experts can greatly improve our analyses. Expert knowledge provides a wealth of otherwise unavailable information and can be useful for SSAs (Smith *et al.* 2018, pp. 307–308), but eliciting such information needs to be done with care (Drescher *et al.* 2013).

Expert Selection

We considered a larger list of potential experts to participate in this exercise. We sought to include highly experienced native fish biologist with a diversity of background and perspectives. We wanted to ensure representation of biologists from both Arizona and New Mexico and include experts from academia and state and Federal agencies. After discussions with individuals on their availability to attend the workshop, we selected 9 experts to participate to participate in the elicitation (Table G-1). Each of them has a wealth of experience in fisheries ecology, and many of them have extensive experience working with the *Gila* species and its habitats throughout Arizona and New Mexico. The elicitation was facilitated by Nathan Allan, FWS, and Conor McGowan, USGS. Other attendees from FWS at the workshop included Ryan Gordon, Mary Richardson, Mike Martinez, and Haley Dykeman.

Table G-1: Participating experts in the 2016 roundtail chub expert elicitation.

Name	Affiliation
Rob Clarkson	Bureau of Reclamation (Phoenix, AZ, Retired)
Shaula Hedwall	U.S. Fish and Wildlife Service (Arizona Ecological Services Office (Flagstaff, AZ)
Yvette Parosz	U.S. Forest Service, Region 3 (Albuquerque, NM)
Kirk Patten	New Mexico Department of Game and Fish (Santa Fe, NM)
Steve Platania	American Southwest Icthyological Research Foundation (ASIR) (Albuquerque, NM)
David Propst	New Mexico Department of Game and Fish (Santa Fe, NM, Retired)
Paul Marsh	Arizona State University Emeritus, Currently Marsh & Associates (Tempe, AZ)
Jeremy Voeltz	U.S. Fish and Wildlife Service, Arizona Fish and Wildlife Conservation Office (Whiteriver, AZ)
Dave Weedman	Arizona Game and Fish Department (Phoenix, AZ)

Expert Preparation

We hosted a series of webinars with the experts and provided information at the beginning of the workshop to prepare them for the elicitation. Included in the preparation materials was information on the decision context, expectations to focus on science, basic biological information on the chubs, and specific background to inform the definitions and assumptions used in the elicitation questions. We began with a discussion of the purpose and approach of the elicitation, as well as the expectations of the participants. The purpose of the elicitation was to provide input for parameters where data is lacking or imprecise to update the model and SSA.

Elicitation Process

The elicitation occurred during a 2-day workshop, June 14-15, 2016, at the BLM Training Center Office in Phoenix, AZ. We elicited expert input through both facilitated group discussions, the 4-step elicitation method and the point-likelihood method. For Questions 1 – 6, we used the 4-step elicitation method because it minimizes frequently occurring problems of anchoring and over-confidence (Speirs-Bridge *et al*. 2010). The 4-step method entails asking experts to first provide their lowest and highest reasonable estimates for the variable in question, followed by their level of confidence (50-100%) that the true value of the variable falls within their stated range (lowest to highest values), and lastly, the most likely estimate. Our general approach for each question was to: 1) explain the question being posed, 2) ask the experts to independently complete the 4-step exercise, 3) compile, summarize, and share the results with the experts, 4) facilitate discussion among the experts, and 5) allow the experts to revise their values, if desired, in additional rounds; most questions only required two rounds. We used a practice question with a fictional, unrelated topic to practice the 4-point elicitation process.

For Question 7, we used the point-likelihood method to rate their confidence in each choice, with the total points of 100. Experts were encouraged to distribute the points consistent with their confidence in the most likely answer to the question. If they were completely confident in an answer, they could enter 100 points; if they were equally divided between the three answers, they could put 33 points in each, and so on.

Although the experts were readily comfortable with identifying themselves, we maintained anonymity during the discussion by displaying values with random numerical designations of experts. We elicited expert input through a facilitated group discussion in response to the first round of answers to each question. During the discussions we highlighted areas of substantial difference and sought explanations for the range in opinions. When applicable, we asked experts whether there may be plausible scenarios in which the values would be outside the bounds of their responses. Experts were encouraged to share their rationale and underlying premises. The purposes of this discussion were to share knowledge among the experts and to allow experts to query one another about outcomes. We emphasized that we were not seeking consensus but rather seeking their individual expert judgment. The discussions allowed us to better understand the sources for the differences in their opinions, identify and reconcile misunderstandings of the question or discrepancies in their knowledge base, and document the breadth of uncertainty. Notes were taken during the discussion. Following the discussion, we asked the experts to complete a “round 2” of answering the questions and providing rationales. We encouraged them to use the information and knowledge gained during the discussion to influence their scores and rationales. In one instance we completed three rounds of scoring.

Expert Elicitation Results

Questions for Experts

We asked the experts seven questions around these primary areas of interest:

1. Current Population Structure
2. Seasonal Stream Length Effects
3. Flood Magnitude and Frequency
4. Nonnative Community Effects
5. Likelihood of Change in Nonnative Community
6. Likelihood of Recolonization
7. Overall Importance of Risk Factors

For each of the seven questions below we report: the wording of the questions and the table to capture responses as provided to the experts at the workshop; a brief background on the topic, summarized from the materials provided to the experts ahead of the workshop; the final round results of the elicitation; and a brief summary of the discussion among the experts during and after the responses. The 'Notes' captured below provide a brief summary of some of the main topics discussed for that question and do not capture the full breadth of the topics discussed.

QUESTION 1. CURRENT POPULATION STRUCTURE

For each of the situations regarding the current population structure (abundance, reproduction, and recruitment) of each chub in individual streams, provide your estimate of the likelihood, from 0 to 100%, that chubs in a single stream could be extirpated over a 10-year period from one or more stochastic events (drought, disease, fire/flood, extreme temperature, etc.). Assume that all other factors for a given stream are equal (equal, typical stream length (~9 km for Headwater; ~17 km for Roundtail); no nonnatives; and no management efforts) and assume no recolonization.

Table G-2: Table to collect expert estimates for Question 1.

Current Population Structure: Likelihood of Extirpation in 10 Years				
	1. Lowest	2. Highest	3. Most Likely	4. Confidence
Pop Condition	(0-100%)	(0-100%)	(0-100%)	(50-100%)
1 - Abundant or Common, Successful Recruitment				
2 - Locally Abundant or Common, Recruitment may be limited				
3 - Uncommon or Rare, Limited Reproduction				

Question 1 Background

Neither density or population size, nor fecundity or survival rates, of chubs are available for most the streams with chubs. Consequently, different metrics are necessary to assess the condition of chub populations or streams. For this current condition category, we reviewed all the available survey and research reports (gray literature) and published literature pertaining to chub survey data from 1990 to 2015. We selected this period for our analysis because it represents a shift in the focus of surveys to look at native species in particular and the reporting record is more robust with information on gear types, survey locations, and providing more information on numbers and sizes of the fish captured. Survey reports used were primarily from Arizona Game and Fish Department (AGFD), New Mexico Department of Game and Fish, the Gila River Native Fish Conservation Program, Bureau of Land Management, and research projects where survey data is presented. Many survey reports did provide qualitative or quantitative descriptions of the presence of chubs and the age or size classes present. There are multiple years of survey data throughout the range of both chub species. However, these surveys varied in target species, equipment, timing, surveyors, duration, and location, and were collected over numerous years. Further, survey reports varied in the information provided.

This metric we constructed for ranking the condition of chub populations uses our understanding of the abundance of chubs and recruitment as an indicator of the health and stability of chub populations over the assessed time period (1990-2015). We used all available survey reports to calculate the abundance and recruitment of chubs. We assumed that survey reports containing indications (visual or by catch) of chub abundance over the assessment period provides a measure of the size of the chub population in the stream. The evaluation of the dataset and its resulting uncertainties and our assumptions for this metric required several complex considerations. This was particularly apparent in the range of data available from survey reports where subjective status (low, common, or abundant) was presented in some reports, and specific numbers of chub present in relation to other fish species was presented in other reports.

We identified three ranking categories for this condition category based on the terminology used in reports and our assessment of the numerical values presented. For the ranking categories, we assume that a stream that supports an abundant population is contributing more value to the species long-term status than one with a low population. The three categories are described in Table G-3.

Table G-3: Ranking criteria for abundance and recruitment of chubs.

Chub abundance and recruitment condition categories	**Ranking**
Data indicates chubs are abundant or common and the population is reproducing with successful recruitment.	1
Data indicates chubs are common or locally abundant, although recruitment may be limited.	2
Data indicates chubs are uncommon or rare and there is limited reproduction and/or recruitment.	3

Our key assumption is that the information available from surveys over time can be used to assess the population structure of chubs in a given stream. While this is generally true, the quality of the data available plays a significant role in the accuracy of the results. Regardless though, these were the only data available at the time to assess chub populations across the range.

Question 1 Responses

The group decided to combine this question for both roundtail and headwater chub responses.

Table G-4: Round 2 results of elicitation from Question 1.

ROUND 2	1 - Abundant or Common, Successful Recruitment				2 - Locally Abundant or Common, Recruitment may be limited				3 - Uncommon or Rare, Limited Reproduction			
Expert	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf
1	10	60	**40**	60	30	70	**50**	60	60	90	**80**	70
2	5	18	**8**	70	10	30	**12**	60	20	60	**40**	60
3	1	10	**2**	95	15	50	**25**	90	30	70	**50**	80
4	5	20	**10**	80	5	50	**20**	90	20	80	**60**	80
5	2	20	**10**	70	3	50	**15**	60	10	80	**20**	50
6	1	5	**2**	75	1	10	**3**	75	5	25	**10**	50
7	1	25	**2**	90	1	50	**5**	90	5	90	**10**	90
8	1	5	**5**	80	2	15	**10**	75	3	25	**20**	50
9	1	5	**2**	90	3	7	**5**	90	5	15	**10**	90
MEDIAN			**5**				**12**				**20**	
AVG			9				16				33	
SD			12				15				25	

Question 1 Notes

As expected, the median result for likelihood of extirpation increased with the categorical population structure decreased in health. The driving factors from the discussion was the expectation of resiliency against stochastic events. Examples of extirpations (and persistence) following large, high intensity wildfires and potential for subsequent post-fire flooding were brought up. While the population structure had some bearing on persistence, the occurrence and magnitude of stochastic events were greater influences on population persistence.

QUESTION 2. SEASONAL STREAM LENGTH EFFECTS

For each of the situations regarding length of streams occupied by chubs during the summer, provide your estimate of the likelihood, from 0 to 100%, that each chub species in a single stream could be extirpated over a 10-year period from one or more stochastic events (drought, disease, fire/flood, extreme temperature, etc.). Assume that all other factors for a given stream are equal (assume the stream has average chub abundance and size classes and no nonnatives or management).

Table G-5: Table to collect expert estimates for Question 2.

Stream Length Effects: Likelihood of Extirpation in 10 Years				
Stream Length (km)	1. Lowest	2. Highest	3. Most Likely	4. Confidence
	(0-100%)	(0-100%)	(0-100%)	(50-100%)
0.5				
3				
6				
10				
15				
20				
30				

Question 2 Background

This metric describes our understanding of the effects of water availability (seasonal stream length and flood frequency and magnitude) on chubs. Habitat quality and quantity data for all streams occupied by chubs is limited. While some data exists on flows and physical conditions of some streams, this data is not consistent or available for all streams and, therefore, not complete enough to use as a metric. Consequently, different metrics are necessary to assess available habitat. The data that is available or can be determined is total stream length, seasonal stream length, and flood frequency and magnitude during various times of the year. Water is the most basic need of individual chubs and populations, as without it, there is no habitat for fish. Thus, for this assessment category, we are focusing on how much water is available in a stream as a surrogate for available habitat with the understanding that stream length is not the main driver of habitat quality. Specifically, we focused our analysis on the length of watered areas in each stream during the season when flows are generally at their lowest. This is typically post-spring runoff and pre-monsoon season, generally May-June. This concept allows us to consider the minimum amount of potential seasonal habitat available for each stream. The amount of watered area at that minimum flow period limits the number of fish that can be supported. Streams that maintain continuous surface flow during the driest period are the highest value (in terms of water availability) for chub.

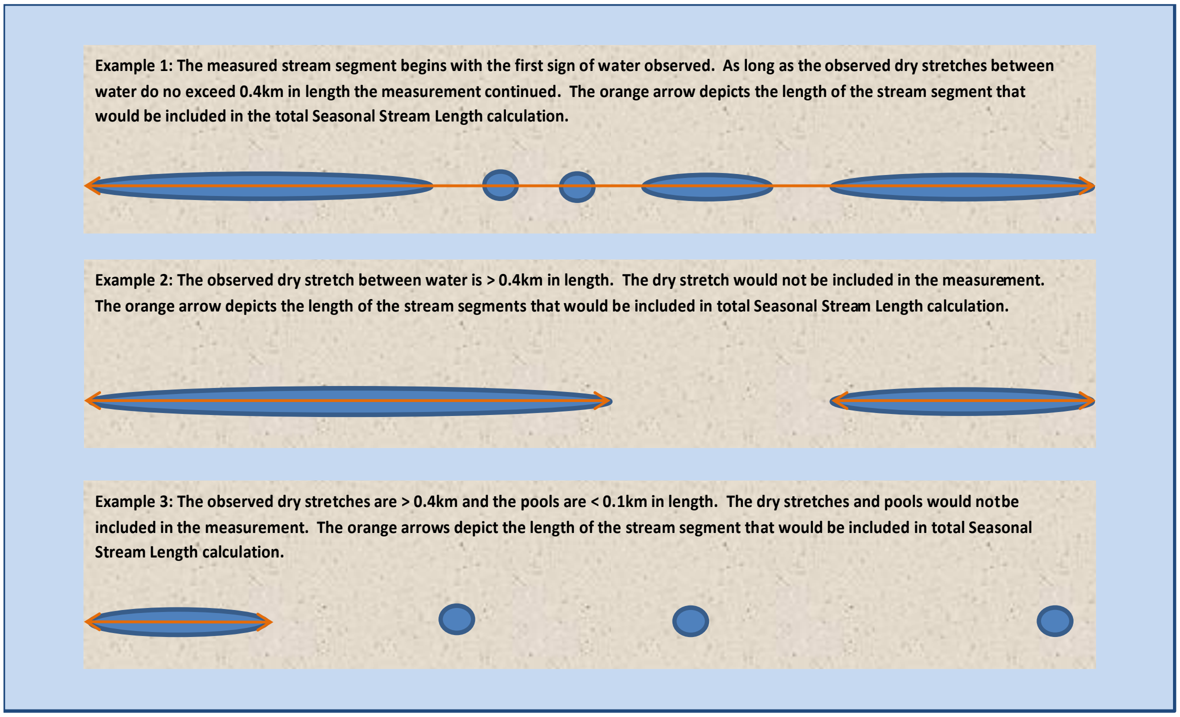
We assume that the longer the stream length the more likely the population will survive a stream drying (Roberts *et al.* 2013, p. 1388) because it is more likely to have some stream reaches not affected by the loss of flow, and it is more likely to have sufficient habitat diversity in the stream to provide refugia for individuals to survive if some reaches become uninhabitable for some time period. The length of a stream needed to support a viable population of chubs is dependent largely on the quality and quantity of preferred habitats present within the length of the stream. There is no scientific research on this topic for chubs; however, we did make use of information from the literature on the management and conservation of the western cutthroat trout (*Oncorhynchus clarki* ssp.) regarding stream lengths needed for successful trout populations (Roberts *et al.* 2013, entire) as well as internal species experts.

Instead of using the previous terms (perennial, interrupted perennial and intermittent) to describe available water in a stream, we describe the Google Earth Pro measurements as Seasonal Stream Length. Seasonal Stream Length was calculated by measuring the available water that can be observed in Google Earth Pro during the driest time of the year. In Arizona, May and June are typically the driest months of the year leading up to the onset of the North American Monsoon. In Arizona, the following Google Earth Pro photo dates that coincide with the May/June seasonal dry periods were 6/7/07, 6/4/10, 6/13/11, 6/24/11, 5/30/12, 6/5/12, 5/28/13, and 6/6/2014. Google Earth Pro photo dates were not consistently available across the range of roundtail and headwater chub in Arizona; therefore, the Month/Year observed in this assessment varies from stream to stream. In New Mexico, the May/June timeframes were not available and therefore we did not provide any Google Earth Pro measurements for those areas.

We calculated the Seasonal Stream Length by measuring the presence of water that was visible on Google Earth Pro as wetted stream segments in May or June. Stream segments were used to describe a measurable stretch of water within a stream. A stream segment was considered measurable as long the observed dry stretches between water did not exceed 0.4km (0.25mi) in length (see Figure G-1, Example 1). If a watered reach was significantly interrupted by dry reaches greater or equal to 0.5km (0.32mi) we concluded the stream segment (see Figure G-1, Example 2). The Seasonal Stream Length was measured from the headwaters to the confluence of another stream. We used the total of all stream segments to calculate the Seasonal Stream Length for each stream. Wetted segments (measuring less than 0.1km) that were isolated by dry segments with a distance greater than 0.4km before contact with the next available water source in a stream were not included in this exercise (see Figure G-1, Example 3). We assumed that the dominance of dry reaches and small wetted reaches in these segments did not allow for any persistent summer connections between the remaining isolated pools, and that wet season connections might also be significantly limited in extent.

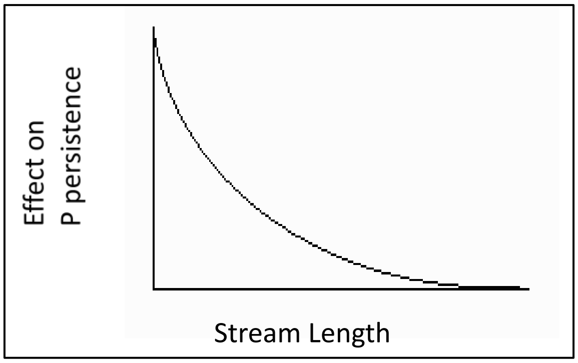
For consistency, only one individual measured the presence of water that was visible on Google Earth Pro. We relied on the best image available for each stream. If we could not provide a reliable estimate of water due to image quality, we did not measure the stream and instead relied on Jones *et al.* (2014) data on estimated perennial water. The extent or potential extent of roundtail and headwater chub distribution within the Seasonal Stream Length was determined by evaluating survey information documenting the absence of chubs in a stream reach, the presence of constructed or natural barriers to chub movement, and known expansion of chub through translocation or natural movement. If there were no known barriers to movement we assumed chubs occupied the entire Seasonal Stream Length. A team of FWS experts analyzed this information to make a determination of the Occupied Seasonal Stream Length.

Figure G-1: Demonstration examples of calculating seasonal stream length.



The relationship between stream length and occupancy probability is curvilinear, a negative exponential relationship. The longer a stream is, the less it effects occupancy.

Figure G-2: Conceptual relationship between stream length and the probability of persistence of chubs in the stream.



Question 2 Responses

Results were collected separately for headwater and roundtail chub during round 1 of answers, but all the experts chose to combine the results for both species in round 2.

Table G-6: Round 2 results of elicitation from Question 2.

ROUND 2	0.5				3				6				10				15				20				30			
Expert	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf
1	10	60	**50**	50	8	40	**30**	55	5	30	**20**	60	4	20	**10**	60	3	15	**5**	80	2	10	**3**	80	1	5	**2**	80
2	20	60	**30**	50	10	50	**20**	50	10	40	**12**	60	10	25	**10**	60	5	15	**7**	70	3	10	**5**	70	2	5	**3**	70
3	15	50	**25**	60	5	40	**10**	70	2	20	**5**	80	1	15	**2**	85	1	15	**2**	90	1	15	**2**	95	1	15	**2**	95
4	10	90	**50**	80	5	15	**25**	60	3	40	**15**	60	2	20	**12**	70	1	10	**5**	70	1	10	**2**	7	1	10	**2**	70
5	1	99	**50**	99	1	90	**25**	90	1	75	**20**	80	1	60	**15**	90	1	45	**10**	90	1	30	**5**	90	1	15	**2**	90
6	50	99	**75**	90	50	90	**50**	90	25	60	**30**	75	10	50	**20**	75	5	20	**10**	90	2	10	**5**	95	1	5	**2**	98
7	10	70	**30**	70	7	35	**15**	75	5	25	**10**	80	4	20	**8**	85	3	15	**5**	90	2	10	**3**	90	1	5	**3**	90
8	25	50	**25**	60	15	40	**20**	70	5	30	**15**	70	4	30	**15**	70	2	10	**2**	70	2	10	**2**	70	1	10	**1**	70
9	10	60	**40**	70	7	20	**10**	75	5	20	**8**	80	1	15	**2**	80	1	15	**2**	85	1	10	**2**	85	1	10	**1**	90
MEDIAN			**40**				**20**				**15**				**10**				**5**				**3**				**2**	
Avg			**42**				**23**				**15**				**10**				**5**				**3**				**2**	
SD			**16.4**				**12.3**				**7.6**				**6.0**				**3.2**				**1.4**				**0.7**	

Question 2 Notes

The experts discussed whether the delineations on the shorter end of stream lengths were sufficient to account for the risk from 0.5 to 3 km in length, but after reviewing the results and additional discussion, the experts decided the breaks were adequate. Experts also discussed examples of extirpated populations that came to mind: for roundtail, this includes the mainstem Little Colorado River from its headwaters down due to drying and nonnative species, reservoirs, groundwater pumping; the Bill Williams River between Alamo Lake and Havasu due to two major reservoirs with nonnatives isolating a 20-mile section of a river; the mainstem Salt River, although chub are sometimes found in the Salt River above Roosevelt. They are still in the tributaries. Also, roundtail are no longer in the system where Roosevelt Reservoir is now located. They have also been extirpated from the New Mexico state line downstream to Yuma in the Gila River. In New Mexico, they are extirpated from the Gila River up to the Forks area. In Deadman Creek, they may be extirpated; data are insufficient to say either way. No one had surveyed thoroughly since the fire there, and it's difficult to access. For Sallie May (a tributary to Roosevelt), there were a lot of surveys completed with none found. Chubs are also not doing well in Eagle Creek.

The results indicate a strong effect in stream length to population persistence, particularly in streams under 10 km.

QUESTION 3. FLOOD MAGNITUDE AND FREQUENCY

For each of the situations regarding average frequency of beneficial flood (years between floods) for individual occupied streams, provide your estimate of the likelihood, from 0 to 100%, that chubs in a single stream could be extirpated over a 10-year period from one or more stochastic events (drought, disease, fire/flood, extreme temperature, etc.). Assume that all other factors for a given stream are equal (equal, typical stream length (~9 km for Headwater; ~17 km for Roundtail); no nonnatives; and no management efforts) and assume no recolonization.

The underlined section of the question was added after discussion with the experts to adapt the question appropriate to the ecological conditions of the species.

Table G-7: Table to collect expert estimates for Question 3.

Flood Frequency: Likelihood of Extirpation in 10 Years				
	1. Lowest	2. Highest	3. Most Likely	4. Confidence
Flood Freq (yrs)	(0-100%)	(0-100%)	(0-100%)	(50-100%)
2				
4				
6				
8				
10				
12				

Question 3 Background

This metric assesses the effects from flooding events that can be beneficial for chub reproduction and recruitment into the subadult/adult population, and thus persistence of chub populations. Though the mechanism is not well known, research has documented a significant increase young roundtail chub in the year following late winter/spring floods and a decrease in young fish without late winter/spring flooding the previous year. A natural hydrograph is an important factor in persistence of native fishes (including roundtail chub) in the Southwest and altered flow regimes present a threat to persistence of chubs via effects to habitat and through changes in the distribution and abundance of nonnative fishes. We elicited the variation in the frequency and magnitude of flooding events and its effect on chub persistence probabilities.

The specific metric we used was the number of years since a ‘beneficial flood.’ A beneficial flood was assumed to be a flow increase of at least 10 times the annual mean daily discharge occurring between January and May. We assume the more years that extend between beneficial floods, the lower overall recruitment for chubs in that stream will be and the more likely the stream could be extirpated from a stochastic event.

Question 3 Responses

Results were collected separately for headwater and roundtail chub although the results are very similar.

Table G-8: Round 2 results of elicitation from Question 2 for headwater chub (top) and roundtail chub (bottom).

HEADWATER																								
ROUND 2	2				4				6				8				10				12			
Expert	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf
1	1	4	**1**	70	1	5	**1**	70	1	6	**1**	80	1	7	**1**	80	1	8	**2**	80	1	10	**3**	80
2	1	2	**1**	90	1	5	**2**	90	1	5	**2**	90	1	10	**5**	85	1	12	**7**	85	1	15	**10**	85
3	1	2	**1**	90	1	5	**1**	90	1	5	**1**	90	1	10	**1**	90	2	10	**2**	90	2	15	**2**	90
4	1	1	**1**	75	1	5	**2**	75	1	10	**5**	75	1	25	**5**	75	1	25	**10**	75	5	30	**5**	75
5	1	5	**2**	70	1	10	**5**	70	1	20	**10**	70	1	25	**10**	70	1	25	**10**	70	1	30	**10**	70
6	1	1	**1**	99	1	1	**1**	99	1	1	**1**	99	1	1	**1**	99	1	2	**1**	95	1	5	**2**	90
7	0	0	**0**	100	0	0	**0**	100	0	0	**0**	100	0	5	**2**	90	0	10	**5**	80	0	15	**7**	70
8	1	3	**1**	90	2	4	**2**	90	2	4	**3**	90	6	10	**6**	75	6	10	**6**	75	6	10	**6**	75
9	1	2	**1**	90	1	3	**1**	80	1	5	**2**	50	1	5	**2**	50	1	10	**3**	50	1	10	**5**	50
MEDIAN			**1**				**1**				**2**				**2**				**5**				**5**	
AVG			**1**				**2**				**3**				**4**				**5**				**6**	
SD			**0.5**				**1.4**				**3.1**				**3.1**				**3.4**				**3.0**	

ROUNDTAIL																								
ROUND 2	2				4				6				8				10				12			
Expert	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf
1	1	4	**1**	70	1	5	**1**	70	1	6	**1**	80	1	7	**1**	80	1	8	**2**	80	1	10	**3**	80
2	1	2	**1**	90	1	5	**2**	90	1	5	**2**	90	1	10	**5**	85	1	12	**7**	85	1	15	**10**	85
3	1	2	**1**	90	1	5	**1**	90	1	5	**1**	90	1	10	**1**	90	2	10	**2**	90	2	15	**2**	90
4	1	1	**1**	75	1	5	**2**	75	1	10	**5**	75	1	25	**5**	75	1	25	**10**	75	5	30	**5**	75
5	1	5	**2**	70	1	10	**5**	70	1	20	**10**	70	1	25	**10**	70	1	25	**10**	70	1	30	**10**	70
6	1	1	**1**	99	1	1	**1**	99	1	1	**1**	99	1	1	**1**	99	1	2	**1**	95	1	5	**2**	90
7	0	0	**0**	100	0	0	**0**	100	0	0	**0**	100	0	0	**0**	100	0	5	**2**	90	0	10	**5**	80
8	1	3	**1**	90	2	4	**2**	90	2	4	**3**	90	6	10	**6**	75	6	10	**6**	75	6	10	**6**	75
9	1	2	**1**	90	1	3	**1**	80	1	5	**2**	50	1	5	**2**	50	1	10	**3**	50	1	10	**5**	50
MEDIAN			**1**				**1**				**2**				**2**				**3**				**5**	
AVG			**1**				**2**				**3**				**3**				**5**				**5**	
SD			**0.5**				**1.4**				**3.1**				**3.3**				**3.6**				**3.0**	

Question 3 Notes

There was recognition among the experts that the flood frequency was a factor that is interrelated to the presence of nonnatives, as large flood events have been shown to limit populations of some nonnatives species and providing an indirect beneficial effect to chubs. Also, the lack of a flood wouldn't cause an extirpation event on its own. And we know chubs can spawn and persist without floods. This is true, but floods have been shown to have benefits to reproductive success, although the exact mechanism is not known for sure. So the presumption would be that as years go by without floods, reproduction and recruitment would, on average, decline and the overall population size would decline as the potential for an extirpation event would increase. If experts disagree with that logic, then that can be communicated through the probabilities provided on the elicitation form.

Part of the motivation for this metric came from input during peer review of the previous SSA where we had several comments from peer reviewers suggesting we need to consider changes to the natural hydrograph. This metric was our attempt to identify what part of the natural hydrograph is important to chub persistence over the long-term. We tried to narrow down the broader hydrograph issue to an appropriate metric that could be included in the model.

One expert explained that there is a relationship between the health of a population and the natural flow regime, and presumably flooding performs several functions that enhance the quality of the habitat, whether it’s restoring and cleansing out sediments or incorporating allochthonous materials. It somehow influences the well-being of the population. If you don’t have a flood for 20 years, will it eliminate a population? Probably not. It’s not as if the lack of the events eliminates the fish, but it’s going to, over time, diminish the quality of habitat. If you just have a flatline hydrograph, eventually the population continues to go downhill, and you increase the risk of it getting extirpated by something else.

The 10-year timeframe for the questions seems to present a challenge given that the lifespan for the species may extend beyond that time. There was some disagreement over the expected lifespan for the fish (some thought that the lifespan was different for headwater and roundtail chubs), ranging from 7 to 20 years. We’ve previously said 7 to 10 years. The point of the question is not that these changes in conditions (loss of flooding) would result in all of the fish dying off, but that decrease in resiliency would result in an increase in the risk of population extirpation from other stochastic events. The question was modified to clarify this understanding. The results reflected the thinking of the majority of experts that the change in hydrograph, measured by fewer peak flows, likely have some small, but measurable, effects on the probability of persistence of chub populations.

QUESTION 4. NONNATIVE COMMUNITY EFFECTS

For each of the situations regarding streams with 3 levels of nonnative community, provide your estimate of the likelihood, from 0 to 100%, that each chub species in a single stream could be extirpated from that stream due **only to** the nonnative community over a 10-year period. Assume that all other factors for a given stream are equal (assume the stream has average chub abundance and size classes; equal, typical stream length (~9 km for Headwater; ~17 km for Roundtail); typical, sufficient flood regime to support reproduction and recruitment; and no other potential threat factors or management) and no recolonization.

Table G-9: Table to collect expert estimates for Question 4.

Nonnative Community Effects: Likelihood of Extirpation over 10 Years				
Nonnative Community	1. Lowest	2. Highest	3. Most Likely	4. Confidence
	(0-100%)	(0-100%)	(0-100%)	(50-100%)
3 - High				
2- Medium				
1 - Low				

Question 4 Background

This metric evaluates our understanding of the effects of competition, predation, and harassment by nonnative species on the chubs. Data or expert knowledge on the presence or absence of nonnatives is available for most streams; however, the population size or density of nonnatives is not known for all streams within the range of the chubs. We relied on published literature, gray literature, and survey reports, along with the best professional judgment of experts familiar with these streams to assess the effects on chubs from specific nonnative species and the level of effect from the nonnative community on chubs within a given stream.

For this metric, we assume that the effects to headwater and roundtail chub from nonnative species are similar to that for other native fish. We base this on the overall literature and our compilation of the potential overlap in habitat and resource use between chubs and nonnative species. Nonnative fish and invertebrate species are well documented as having a potential for adverse effects ranging from minor (effects to a few individual fish) to extreme (effects at a level sufficient to extirpate a population) to populations of native fish species in Arizona and across the Southwest. We recognize that local habitat conditions influence the relationship of specific nonnatives to chubs, and those actual effects will vary by stream and over time. We further recognize that there are streams containing chubs and nonnatives that have co-occurred for decades under what must be suitable conditions and that the reasons for this continued co-occurrence is not understood.

This analysis does not include an evaluation of abundance data of nonnatives in streams as this information is not available for many streams. A further complication is that we cannot form an assumption that after a certain population size, a particular nonnative species becomes more of a threat to chubs. Additionally, because there are situations were both species co-occur with varying population sizes and that is likely the result of local physical habitat conditions, our uncertainty in setting a metric of nonnative population size was very high. As a result, for this metric we focused on the degree of potential effects of nonnatives on chubs, not on the site-specific responses, since these are variable (Table G-10). We acknowledge that in doing this the rankings represent the theoretical maximum level of effects possible.

We identified four ranking categories: very high, high, moderate, and low (Table G-11). There are nonnative species that demonstrate a high level of effect to chubs and those that demonstrate a low level. However, there are those nonnatives that demonstrate a moderate effect to chubs. To capture these levels of effects we identified four value rankings to assess the effects from specific nonnatives to chubs. The ranking values in Table G-11 represent our understanding of the effects of the specific nonnative species to chub. FWS biologists familiar with chubs and nonnative species ranked the effects of the specific nonnative communities to chubs in a given stream.

Table G-10: Nonnative species and their potential effects on chubs.

Nonnative Species	Age Classes of Chub Preyed on By Nonnative Species	Sizes of Nonnatives That Prey on Chubs	Nonnative Habitat Overlap With Chubs	Competition: Harassment (Displacement and/or Injury)
Black bullhead	Larvae to juvenile	Adults	Yes: also defends nests	Displace from pool habitat. Consumes invertebrates.
Brown trout (wild)	Larvae to sub-adult	Sub-adult to adult	Yes: pools	Consumes invertebrates.
Bullfrog	Larvae to juvenile	Adults	Yes: uses shallow margin areas	Found mostly in shallow waters where YOY or small juveniles may be present.
Channel catfish	Juveniles to sub-adults	Adults	Yes: deep water areas	Uses deep, quite habitat. Consumes invertebrates.
Common carp	Eggs primarily	Sub-adult to adult	Yes: uses most habitat types	Consumes invertebrates.
Crayfish	Larvae, small sub-adult	Adults	Yes: uses all habitat types	Attacks fish that come too close, will injure/kill fish that cannot escape from them. Aggressive defender of shelter. Consumes invertebrates.
Green sunfish	Larvae to juveniles	Juveniles to adults	Yes: uses multiple habitat types	Consumes invertebrates.
Fathead minnow	Larvae	Adults	Yes: uses slow water habitats	Consumes invertebrates.
Flathead catfish	Sub-adults and adults	Sub-adult, adult	Yes: uses slow and deep areas	Consumes invertebrates.
Largemouth bass	Larvae to sub-adults	Sub-adult to adult	Yes: low velocity areas	Consumes invertebrates.
Mosquitofish	Larvae	Adults	Yes: shallow vegetated areas	Displaces from pool habitat.
Rainbow trout (wild)	Larvae to juveniles	Adults	Yes: pools	Uses pool habitat.
River otter	Sub-adult to adult; chub may not be preferred prey due to their speed.	Sub-adult to adult	Uses all habitats	Attacks fish that come too close, will injure/kill fish that cannot escape from them
Red shiner	Larvae	Adult	Yes: shallow habitats	Consumes invertebrates.
Rock bass	Larvae to juveniles	Sub-adult to adult	Yes: pools	Uses pool habitat. Consumes invertebrates.
Smallmouth bass	Larvae to sub-adults	Sub-adult to adult	Yes	Prefers pools with cover, intolerant of turbidity, may exclude chub from preferred pools. Consumes invertebrates.
Yellow bullhead	Larvae to juvenile	Sub-adult to adult	Yes	Uses pool habitat. Defends nest and young. Consumes invertebrates.

Table G-11: Ranking criteria for nonnative species effects on chubs.

Category Effect	Qualitative Assessment of Magnitude of Effects	Nonnative Species in Category
Very high	Potential for high levels of predation on more than one chub size classes by one or more nonnative species size classes that increase with population size of the nonnative species; high overlap in preferred habitats with chub that leads to competition and harassment displacing chub from preferred habitats.	Green sunfish, flathead catfish, smallmouth bass
High	Potential for moderate to high levels of predation on one or more chub size classes by one or more nonnative species size classes that increase with population size of the species; moderate amount of habitat overlap with chubs that leads to competition and harassment displacing chub from preferred habitats.	Black bullhead, yellow bullhead, brown trout, largemouth bass, crayfish
Moderate	Potential for low to moderate levels of predation on one or more chub size classes regardless of size of population; low level of habitat overlap has limited opportunity for competition or harassment.	Channel catfish, rainbow trout, rock bass, red shiner, western mosquitofish, river otter
Low	Low risk of predation on and competition for habitat with chub.	Bullfrog, common carp, fathead minnow

This metric evaluates our understanding of the level of effects from the particular nonnative community present in a stream on chubs. Our first level assumption is that chub in streams with more “high effect” nonnative species are at a higher risk of negative effects than chub in streams with no or fewer nonnative species with high effects to chubs. For example, if black bullhead, green sunfish, and smallmouth bass are all present in a given stream there is a greater probability that chubs will be in smaller numbers, have fewer recruitment events, and be less able to recover from the effects of additional stressors than in streams with a community of lower ranking nonnatives. As noted earlier, there are streams where chubs and the nonnative community are co-existing successfully. The local physical and biological conditions are likely the primary drivers of this co-existence. We do not understand these complex interactions, but we acknowledge that the presence of nonnative species does not automatically result in significant adverse effects to chub populations.

We used three ranking classes for each stream: high, medium, and low (Table G-11). In this metric, FWS biologists reviewed the suite of nonnative species present in each stream and, based on the nonnative species present and their knowledge of the potential consequences of that community on chubs, considered the synergistic effects of that community on chubs’ reproductive success, recruitment and ultimately on long term abundance. The ranking was based on our understanding of the available information and our best professional judgment.

Table G-12: Ranking of nonnative community on chub populations.

Numeric Value	Qualitative Value	Qualitative Description
3	**High**	Nonnative community contains several very high or high impact species that may work cumulatively to have significant adverse effects on chub populations
2	**Medium**	Nonnative community contains a mix of high and moderate impact species that may work in synergy to have adverse effects on chub populations.
1	**Low**	Nonnative community contains a mix of mostly low impact species that together have a more limited affect to chub populations, primarily effects to individuals.

Question 4 Responses

We conducted three rounds of scoring on this question as there was a wide range of estimates and a robust discussion about the issue. We report the results from the final round.

Table G-13: Round 3 results of elicitation from Question 4 for headwater chub (top) and roundtail chub (bottom).

HEADWATER												
ROUND 3	**3 - High**				**2 - Medium**				**1 - Low**			
Expert	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf
1	5	60	**20**	70	5	30	**15**	80	5	15	**10**	70
2	5	99	**33**	75	5	60	**10**	75	1	10	**2**	75
3	50	90	**65**	80	20	50	**30**	80	5	15	**10**	60
4	30	80	**50**	75	10	30	**20**	70	5	20	**10**	65
5	40	100	**75**	90	10	50	**30**	90	1	10	**2**	90
6	10	99	**20**	95	5	50	**10**	75	2	25	**5**	75
7	10	40	**20**	80	4	15	**5**	95	1	5	**2**	95
8	10	30	**15**	80	5	15	**10**	80	1	5	**3**	85
9	20	90	**50**	90	10	50	**30**	70	1	20	**10**	80
MEDIAN			**33**				**15**				**5**	
AVG			**39**				**18**				**6**	
SD			**22.1**				**10.0**				**3.9**	

ROUNDTAIL												
ROUND 3	3 - High				2 - Medium				1 - Low			
Expert	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf
1	6	30	**8**	70	4	12	**6**	70	2	8	**3**	70
2	5	99	**33**	75	5	60	**10**	75	1	10	**2**	75
3	25	75	**50**	70	10	30	**20**	70	5	20	**15**	75
4	35	95	**75**	70	20	50	**30**	65	10	25	**15**	60
5	50	100	**75**	90	20	50	**30**	90	5	20	**5**	75
6	10	99	**20**	95	5	50	**10**	75	2	25	**5**	75
7	10	40	**20**	80	5	30	**5**	75	1	5	**2**	75
8	20	60	**50**	75	10	30	**20**	75	2	10	**5**	75
9	10	70	**25**	80	5	50	**15**	70	1	20	**5**	70
MEDIAN			**33**				**15**				**5**	
AVG			**40**				**16**				**6**	
SD			**24.4**				**9.5**				**5.1**	

Question 4 Notes

Are there examples where chubs have been extirpated by nonnatives in less than 10 years? East Fork of the Gila due to a small population of smallmouth bass; upper Salt River and middle Gila upstream of state line, both due to flathead catfish; some reservoirs. Smallmouth were stocked into Black River in the early 1960s, and the chubs in a portion of the river crashed pretty quickly, but there are still chubs there. They haven't recovered in some areas, but in some portions they're doing alright. Eagle Creek was invaded by smallmouth bass and chubs persisted. Then smallmouth bass disappeared, and chubs are still present. In Turkey Creek, chubs only occurred above a series of water falls and hot springs, and smallmouth bass were downstream, and there were no chubs. Then the Dry Lakes Fire happened, and there were a few chubs that survived the fire, but smallmouth didn't, and for a while, there was a nice population of chubs downstream where smallmouth used to be. In some of the bigger systems, there used to be chubs all the way down the Gila and the Salt, and they're now gone due to a combination of several things, with nonnatives being one cause.

Some experts questioned that the risk could be as high as 75%; what does that mean? It means, roughly, in any given year the risk of a stream with these effects of nonnatives has a 7.5% chance of extirpation. Over 10 years, you would expect ¾ of streams in this condition to be become extirpated. Some experts thought that was highly improbable, but others disagreed. Ten years is a short time to consider effects; 20 years might be a better timeframe to consider.

We noted that there is somewhat of a bimodal distribution of estimates from the experts with 4 estimating the effects of High nonnatives at 25% or less and 4 estimating 50% or greater, with only one expert in the middle (33%). Recognizing the wide range of estimates, we did three rounds of scoring for this question.

QUESTION 5. LIKELIHOOD OF CHANGE IN NONNATIVE COMMUNITY

What is the likelihood that a stream with one level of nonnative community could change, over 10 years, to another level of nonnative community? Assume that there are no management efforts that change the nonnative community and that there is some hydrologic connection to other streams. We expect mechanisms of increase are intentional movement, accidental movements, and natural range expansions. Mechanisms of decrease would be due to natural stochastic eliminations of populations.

Table G-14: List of possible transitions in nonnative community categories (Table G-11 above provides definition of the three categories).

Nonnative Community Change in Category	**Possible Transitions**
Three Increase	0 to 3
Two Increase	0 to 2; 1 to 3
One Increase	0 to 1; 1 to 2; 2 to 3
One Decrease	3 to 2; 2 to 1; 1 to 0
Two Decrease	2 to 0; 3 to 1
Three Decrease	3 to 0

Table G-15: Table to collect expert estimates for Question 5.

Change in Nonnative: Likelihood of Change in 10 Years				
Change in Category	1. Lowest (0-100%)	2. Highest (0-100%)	3. Most Likely (0-100%)	4. Confidence (50-100%)
Three Increase				
Two Increase				
One Increase				
One Decrease				
Two Decrease				
Three Decrease				

Question 5 Background

This question was intended to estimate the potential for the nonnative communities to change in the future outside of intentional management actions. As the presence of nonnatives is an important factor to consider in the status of the chubs, we wanted to estimate the chances that the conditions in streams would change. Using our three categories of nonnatives, plus a 'zero' category for no nonnatives present; what are the chances the category would increase or decrease over the next 10 years. Table G-15 shows the potential combinations of changes.

Question 5 Responses

Because of the large number of circumstances to score (12), we only asked the experts to provide a most likely response. Also, two experts had to leave the workshop, so the total estimates were reduced from 9 to 7.

Table G-16: Round 2 results of elicitation from Question 5 for headwater chub (top) and roundtail chub (bottom).

Headwater												
ROUND 2	MOST LIKELY			MOST LIKELY			MOST LIKELY			MOST LIKELY		
Expert	3 to 2	3 to 1	3 to 0	2 to 3	2 to 1	2 to 0	1 to 2	1 to 3	1 to 0	0 to 1	0 to 2	0 to 3
1	1	1	1	10	5	5	20	10	5	10	10	10
2	5	2	0.5	15	10	0.5	15	15	0.5	15	15	15
3	2	1	1	5	2	1	5	2	1	5	2	1
4	3	1	2	20	10	5	10	25	10	10	10	25
5	1	1	1	30	1	1	5	30	1	10	10	30
6	1	1	1	40	1	5	25	25	1	20	20	20
7	5	2	1	50	10	5	40	50	5	24	24	50
MEDIAN	**2**	**1**	**1**	**20**	**5**	**5**	**15**	**25**	**1**	**10**	**10**	**20**
AVG	**2.6**	**1.3**	**1.1**	**24.3**	**5.6**	**3.2**	**17.1**	**22.4**	**3.4**	**13.4**	**13.0**	**21.6**
SD	**1.8**	**0.5**	**0.4**	**16.4**	**4.4**	**2.2**	**12.5**	**15.6**	**3.5**	**6.6**	**7.3**	**15.8**

Roundtail												
ROUND 2	MOST LIKELY			MOST LIKELY			MOST LIKELY			MOST LIKELY		
Expert	3 to 2	3 to 1	3 to 0	2 to 3	2 to 1	2 to 0	1 to 2	1 to 3	1 to 0	0 to 1	0 to 2	0 to 3
1	1	1	1	10	5	5	20	10	5	10	10	10
2	5	2	0.5	15	10	0.5	15	15	0.5	15	15	15
3	2	1	1	5	2	1	5	2	1	5	2	1
4	3	1	2	20	10	5	10	25	10	10	10	25
5	1	1	1	40	1	1	10	40	1	20	20	30
6	1	1	1	40	1	5	25	25	1	20	20	20
7	5	2	1	50	10	5	40	50	5	24	24	50
MEDIAN	**2**	**1**	**1**	**20**	**5**	**5**	**15**	**25**	**1**	**15**	**15**	**20**
AVG	**2.6**	**1.3**	**1.1**	**25.7**	**5.6**	**3.2**	**17.9**	**23.9**	**3.4**	**14.9**	**14.4**	**21.6**
SD	**1.8**	**0.5**	**0.4**	**17.4**	**4.4**	**2.2**	**11.9**	**16.8**	**3.5**	**6.8**	**7.6**	**15.8**

Question 5 Notes

One expert thought that nonnatives have had an opportunity to move around and get where they are going to be, so the overall probability of changing from the current condition should be low. Overall, the chances of things getting worse were higher than conditions improving.

QUESTION 6. LIKELIHOOD OF RECOLONIZATION

What is the likelihood that a stream that was once occupied by chubs, but is extirpated, will be recolonized through natural dispersal over the next 10 years as a function of the number of occupied streams hydrologically connected to that stream? Assume that there are no management efforts to recolonize an extirpated stream.

Table G-17: Table to collect expert estimates for Question 6.

Connectivity: Likelihood of Recolonization in 10 Years				
Connected Streams	1. Lowest (0-100%)	2. Highest (0-100%)	3. Most Likely (0-100%)	4. Confidence (50-100%)
0				
1				
2				
4				
8				

Question 6 Background

We used this question to evaluate the potential for recolonization if a currently occupied stream becomes extirpated. We evaluate this potential based on the number of occupied streams that are connected to an extirpated stream. If a stream became extirpated, and it had no hydrologically connected stream, what are the chances, without management intervention, that the stream would be recolonized. What if the extirpated stream is connected to 1 other source population, what is the likelihood of it becoming recolonized? If a stream is connected to 2 other source populations, what is the likelihood of it becoming recolonized? And so on.

Question 6. Responses

Table G-18: Round 2 results of elicitation from Question 6 for headwater chub (top) and roundtail chub (bottom).

HEADWATER																				
ROUND 2	0				1				2				4				8			
Expert	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf
1	0	0	**0**	99	1	2	**1**	85	1	4	**2**	75	2	8	**3**	55	4	16	**5**	50
2	0.5	2	**0.5**	90	1	10	**2**	90	1	10	**5**	70	1	20	**10**	50	5	25	**15**	50
3	0	1	**0**	100	1	5	**3**	50	4	10	**5**	50	5	50	**40**	60	5	80	**70**	80
4	0	0.5	**0.1**	90	0	1	**0.2**	90	0	2	**0.4**	85	0	3	**0.8**	80	0	4	**1.6**	75
5	0	2	**1**	90	10	50	**20**	80	20	60	**40**	80	50	70	**60**	80	60	80	**70**	80
6	0	5	**1.00**	90	10	40	**15**	90	25	50	**35**	80	50	75	**60**	80	60	90	**75**	80
7	0.1	0.1	**0.1**	99.1	1	50	**15**	60	10	70	**35**	75	50	99	**75**	80	70	99	**85**	85
8	0.1	0.1	**0.1**	99	1	99	**5**	50	10	99	**10**	75	25	99	**25**	75	50	99	**50**	95
9	0	0	**0**	100	1	20	**10**	70	10	30	**20**	70	30	50	**40**	70	40	70	**60**	70
MEDIAN			**0.1**				**5**				**10**				**40**				**60**	
AVG			**0.3**				**8**				**17**				**35**				**48**	
SD			**0.4**				**7.3**				**15.9**				**27.0**				**32.2**	

ROUNDTAIL																				
ROUND 2	0				1				2				4				8			
Expert	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf	Low	High	**ML**	Conf
1	0	0	**0**	99	1	2	**1**	85	1	4	**2**	75	2	8	**3**	55	4	16	**5**	50
2	0.5	5	**1**	90	1	15	**5**	90	1	30	**20**	70	1	55	**40**	50	5	60	**50**	50
3	0	1	**0**	100	1	5	**3**	50	4	10	**5**	50	5	50	**40**	60	5	80	**70**	80
4	0	0.5	**0.1**	90	0	1	**0.2**	90	0	2	**0.4**	85	0	3	**0.8**	80	0	4	**1.6**	75
5	0	1	**0**	90	10	40	**30**	75	25	60	**40**	75	50	70	**60**	75	60	80	**70**	75
6	0	5	**1.00**	90	10	40	**15**	90	25	50	**35**	80	50	75	**60**	80	60	90	**75**	80
7	0.1	0.1	**0.1**	99.1	1	50	**15**	60	10	70	**35**	75	50	99	**75**	80	70	99	**85**	85
8	0.1	0.1	**0.1**	99	1	99	**5**	50	10	99	**10**	75	25	99	**25**	75	50	99	**50**	95
9	0	0	**0**	100	1	20	**10**	70	10	30	**20**	70	30	50	**40**	70	40	70	**60**	70
MEDIAN			**0.1**				**5**				**20**				**40**				**60**	
AVG			**0.3**				**9.4**				**18.6**				**38.2**				**51.8**	
SD			**0.4**				**9.5**				**15.3**				**25.3**				**29.8**	

Question 6 Notes

One expert asked, shouldn't the relationship be a linear increase with the number of connected streams? Another answered, no, the relationship caps out, at some point adding more streams doesn't increase recolonization potential. We recognized that we know little about the movement; it is thought that adults don't move a lot and have site fidelity, but we assume that young fish will disperse as habitats are available.

Experts differed on how to view the question. Some felt strongly the question about recolonization implied that their score included an assessment of both the chances of fish moving to an occupied area AND the chances it becomes established for some time as a new population. The occupancy model should evaluate the persistence in the future as part of the process, so the experts were advised to consider the question primarily around the chances of movement between streams, however, not everyone agreed to look at the question in that way.

QUESTION 7. OVERALL IMPORTANCE OF RISK FACTORS

Given all the factors we are considering influencing the probability of persistence for chub populations, provide your belief about the importance of each factor.
Assign a relative score of the importance of each of these factors by distributing 100 points among each of the factors. The points represent your strength of belief that the answer is correct. For each factor, the sum should total 100.

Table G-19: Table to collect expert estimates for Question 7.

Importance to Chub Persistence			
Factors	**Not Very Important**	**Somewhat Important**	**Very Important**
Population Structure			
Seasonal Stream Length			
Flood Frequency			
Nonnative Community			
Connectivity/ Recolonization			

Question 7 Background

This is a different type of question. The results will not be used in the model, but instead are intended as an overall check of the opinion of the experts of the relative importance of the various factors we are considering in the model. This question combined the thoughts for headwater chub and roundtail chub.

Question 7 Responses

Table G-20: Round 2 results of elicitation from Question 7.

ROUND 2	**Population Structure**			**Seasonal Stream Length**			**Flood Frequency**			**Nonnative Community**			**Connectivity / Recolonization**		
Expert	Not Very Important	Somewhat Important	Very Important	Not Very Important	Somewhat Important	Very Important	Not Very Important	Somewhat Important	Very Important	Not Very Important	Somewhat Important	Very Important	Not Very Important	Somewhat Important	Very Important
1	0	10	90	25	50	25	0	50	50	0	10	90	25	50	25
2	10	20	70	10	40	50	30	40	30	5	5	90	10	70	20
3	20	60	20	40	40	20	0	10	90	20	20	60	30	50	20
4	10	80	10	0	20	80	50	30	20	0	0	100	80	15	5
5	0	35	65	0	35	65	0	20	80	0	20	80	50	25	25
6	33	34	33	20	60	20	20	60	20	2	3	95	75	15	10
7	30	60	10	10	30	60	30	50	20	10	30	60	30	60	10
8	0	10	90	0	80	20	0	10	90	0	0	100	0	25	75
9	5	10	85	5	15	80	5	25	70	5	15	80	5	20	70
MEDIAN	**10**	**34**	**65**	**10**	**40**	**50**	**5**	**30**	**50**	**2**	**10**	**90**	**30**	**25**	**20**
AVG	**12**	**35**	**53**	**12**	**41**	**47**	**15**	**33**	**52**	**5**	**11**	**84**	**34**	**37**	**29**
STD	**13**	**26**	**34**	**14**	**20**	**26**	**18**	**18**	**31**	**7**	**10**	**15**	**29**	**21**	**26**

Table G-21: Summary of overall importance of chub risk factors, sorted in order of the average score for the *Very Important* ranking.

2016 Chub Elicitation	Average Scores (N=9)			
Factor	Very Important	*SD*	Somewhat Important	Not Very Important
Nonnative Community	84	*15*	11	15
Population Structure	53	*34*	35	12
Flood Frequency	52	*31*	33	15
Seasonal Stream Length	47	*26*	41	12
Connectivity/Recolonization	29	*26*	37	34

Question 7 Notes

The results are not surprising. Nonnative community scored as the most important factor with the lowest amount of variability. All of the factors were at least somewhat important.

References Cited

All references are available in Appendix I of the Roundtail Chub SSA Report.

APPENDIX H: PROBABILITY OF PERSISTENCE MAPS

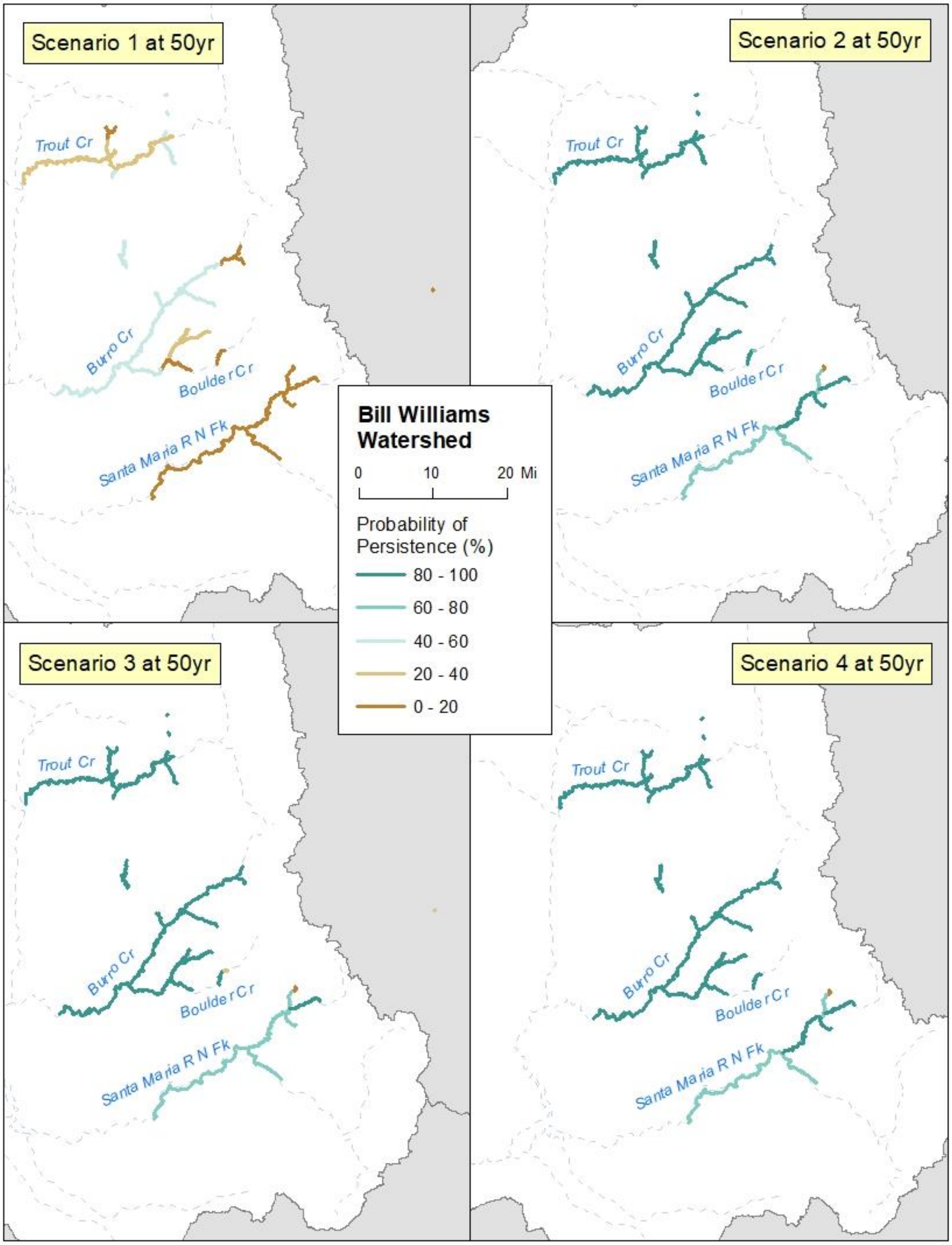


Figure H-1: Projected probability of persistence in 50 years under each of the four future scenarios for currently occupied streams (PMUs) in the Bill Williams River watershed.

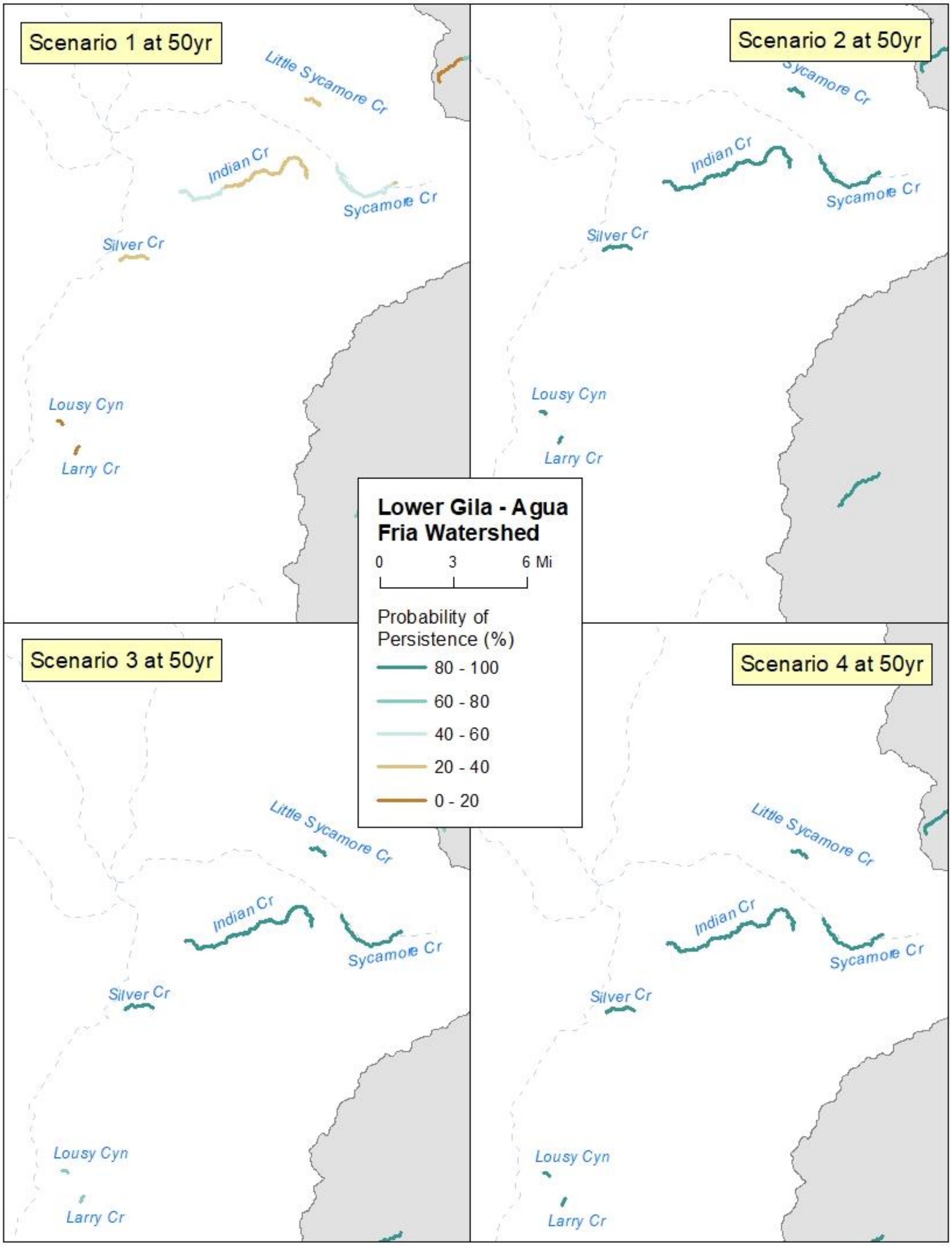


Figure H-2: Projected probability of persistence in 50 years under each of the four future scenarios for currently occupied streams (PMUs) in the Lower Gila-Agua Fria watershed.

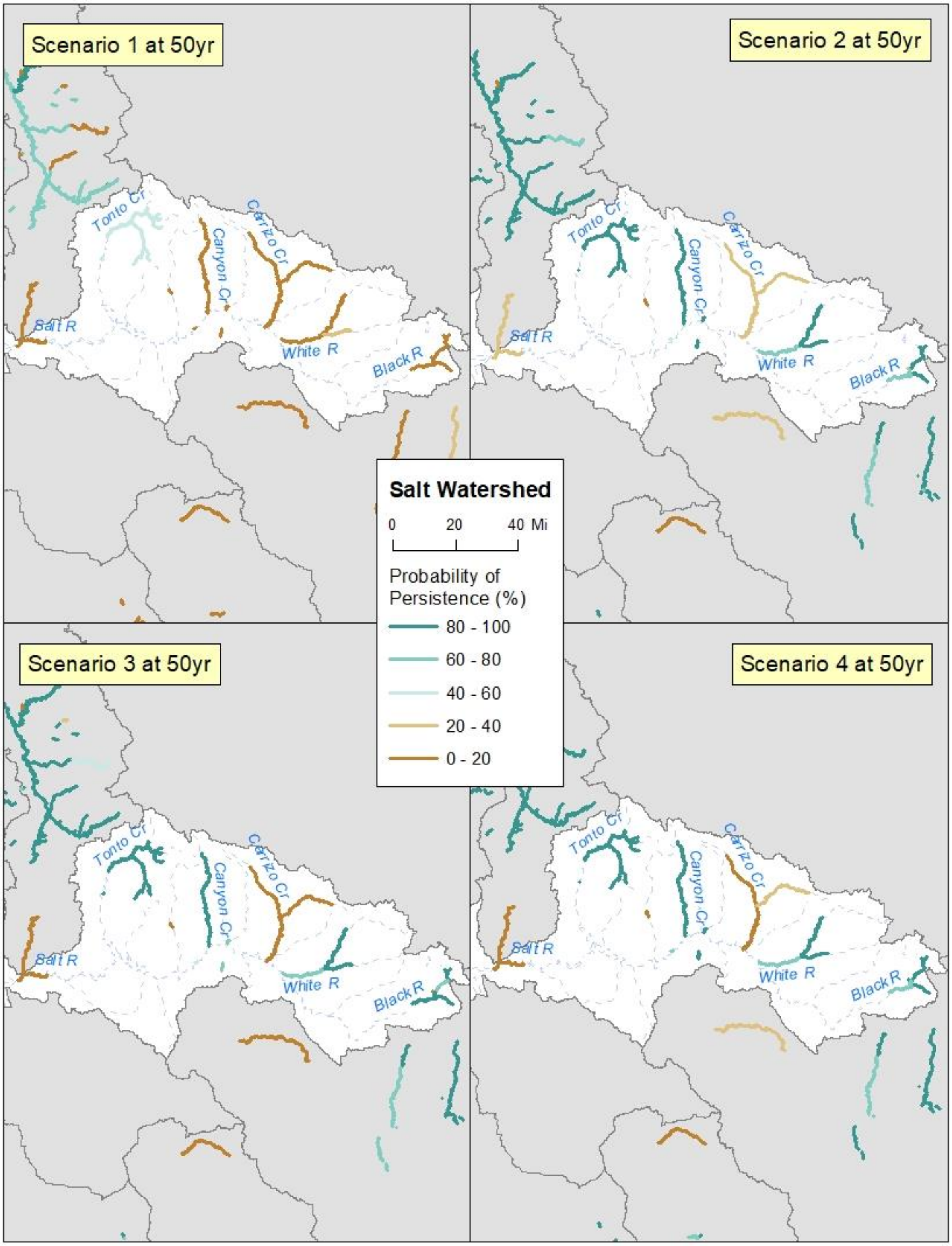


Figure H-3: Projected probability of persistence in 50 years under each of the four future scenarios for currently occupied streams (PMUs) in the Salt River watershed.

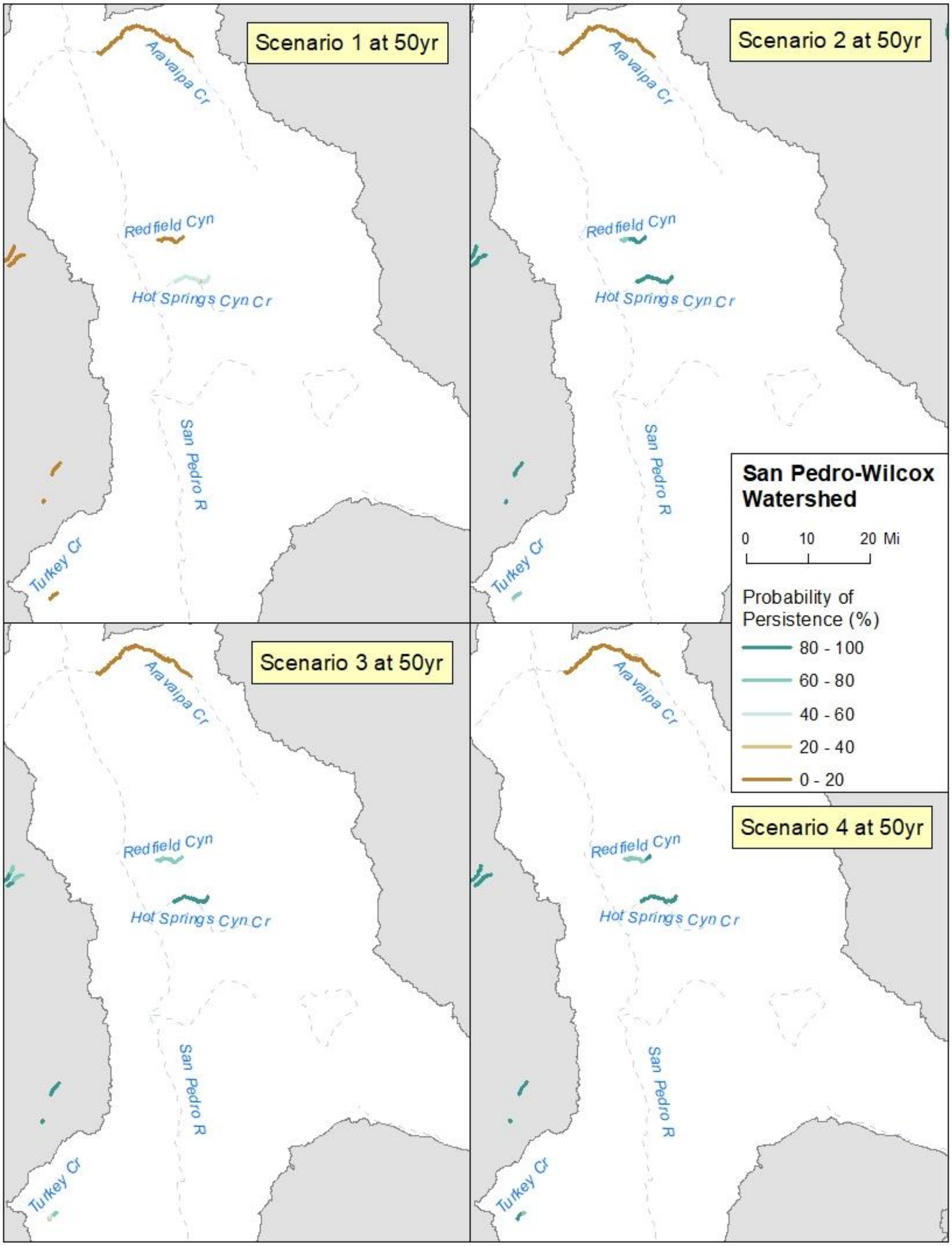


Figure H-4: Projected probability of persistence in 50 years under each of the four future scenarios for currently occupied streams (PMUs) in the San Pedro-Wilcox watershed.

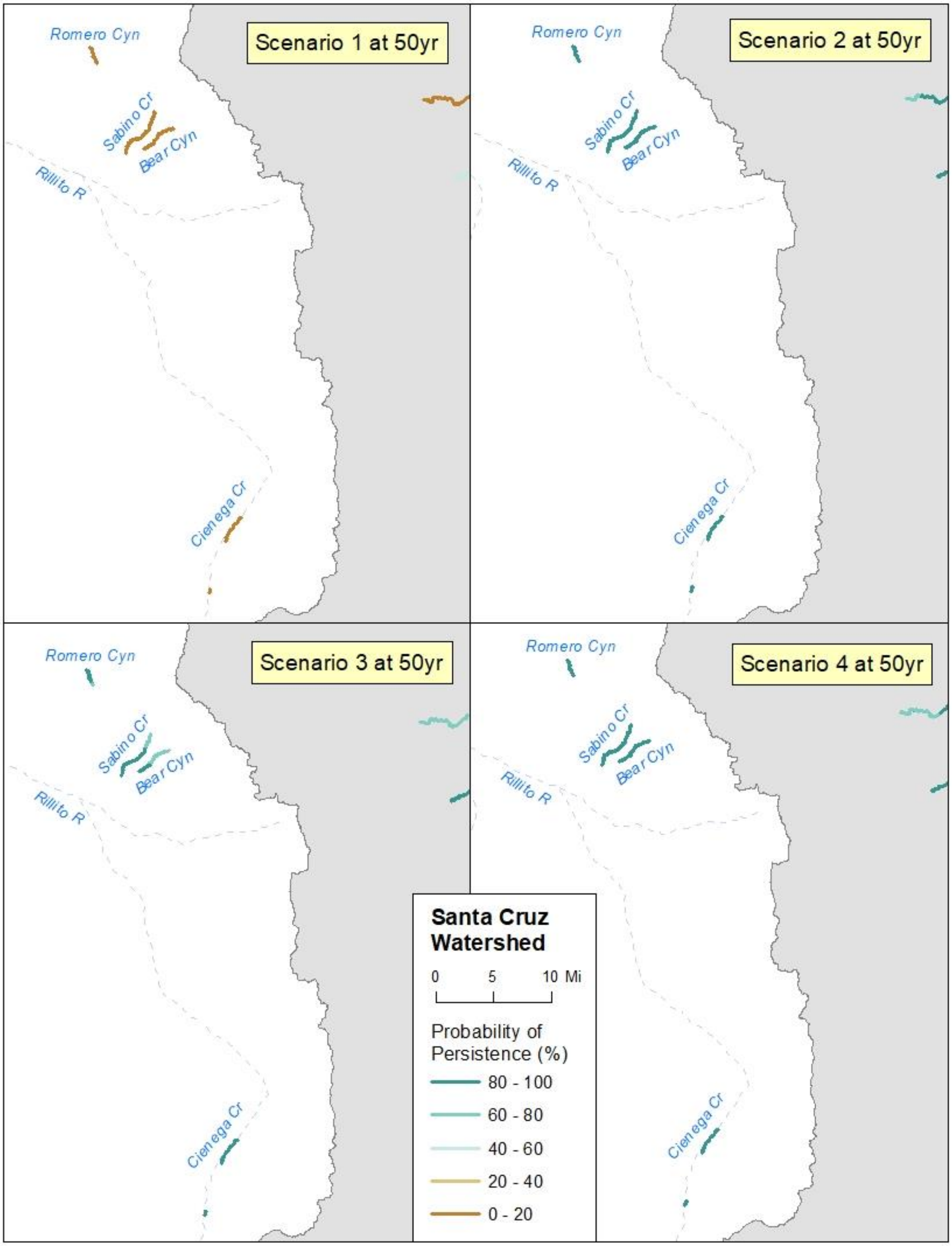


Figure H-5: Projected probability of persistence in 50 years under each of the four future scenarios for currently occupied streams (PMUs) in the Santa Cruz River watershed.

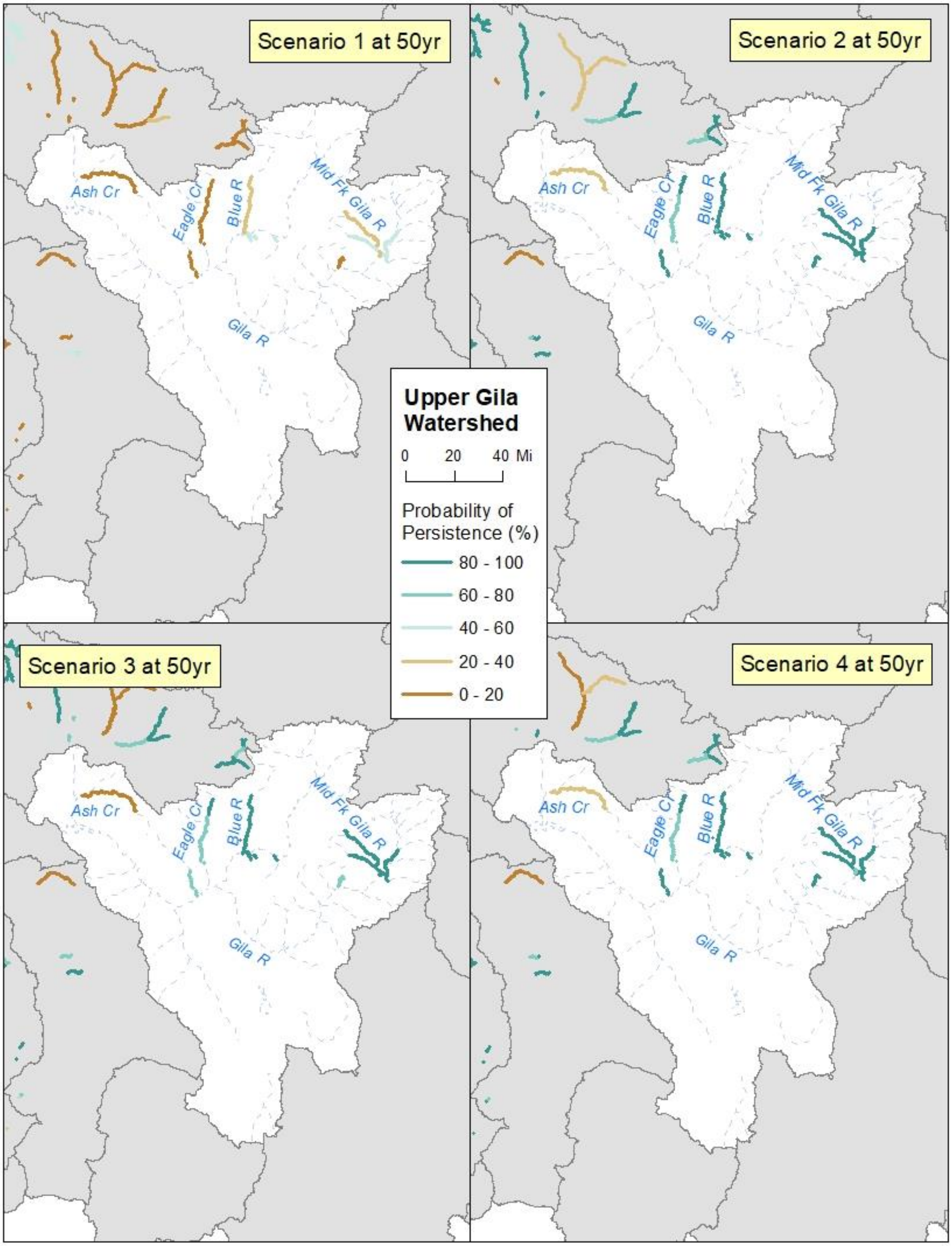


Figure H-6: Projected probability of persistence in 50 years under each of the four future scenarios for currently occupied streams (PMUs) in the Upper Gila River watershed.

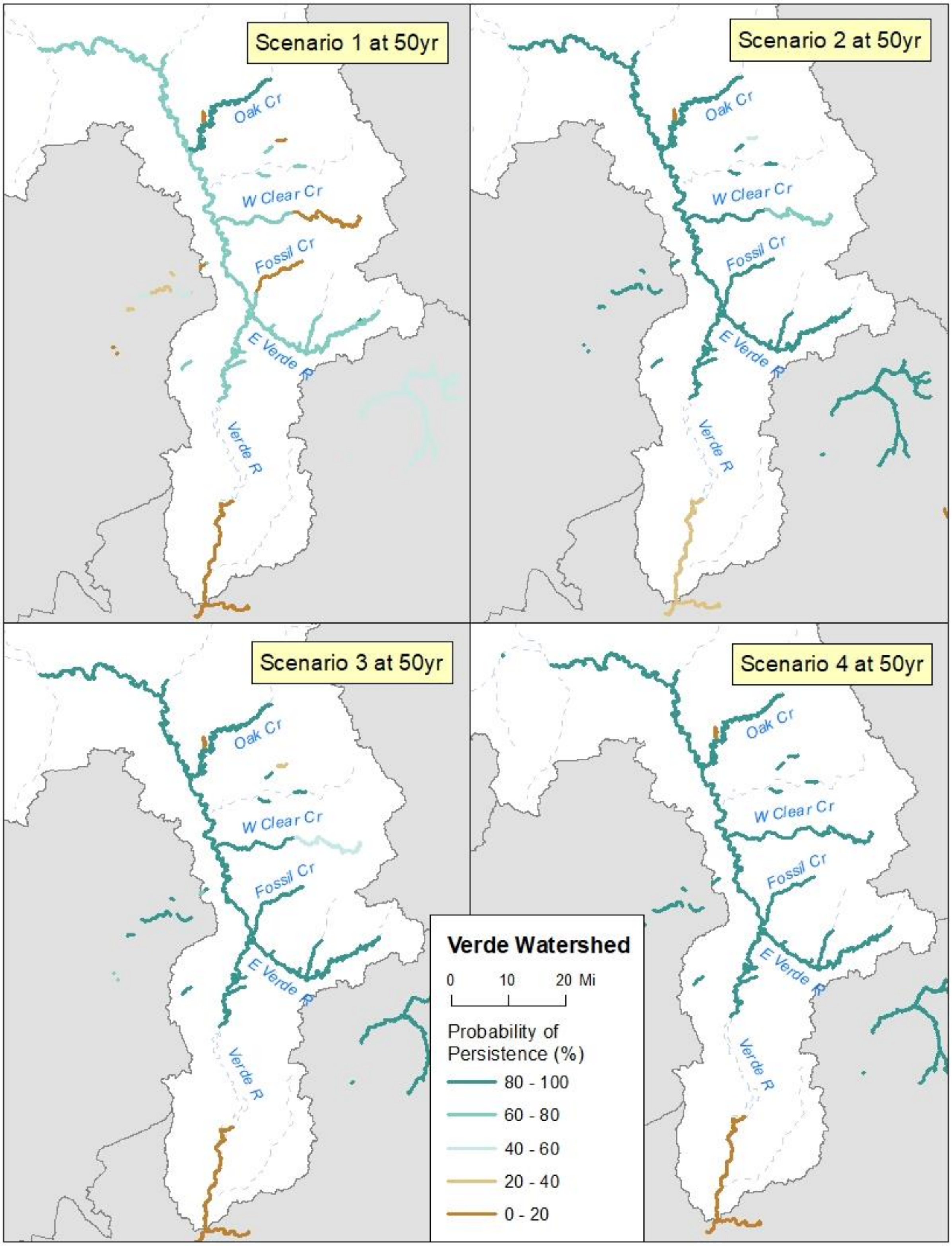


Figure H-7: Projected probability of persistence in 50 years under each of the four future scenarios for currently occupied streams (PMUs) in the Verde River watershed.

APPENDIX I: LITERATURE CITED

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