Species Status Assessment Report

for the

Three Forks springsnail (*Pyrgulopsis trivialis*)

Version 1.0

November 2023

U.S. Fish and Wildlife Service

Arizona Ecological Services Field Office

Phoenix, AZ

Disclaimer:

This document was prepared by Nichole Engelmann and Janess Vartanian (USFWS) and Jeff Sorensen, Arizona Game and Fish Department (AZGFD). Analysis support was provided by Matthew Boggie and Daniel Bunting (USFWS).

Valuable input was provided by Emma Young and Amanda Murnane (USFWS). Partner and Peer reviews of this document's draft were solicited and received. Partner reviews were provided by Whitney Heuring and Nora Clark and peer reviews were provided by and Mike Martinez, Terry Myers, Ellen Soles PhD, and Kathryn Perez PhD. We appreciate their input and comments, which resulted in a more robust Species Status Assessment report.

Recommended reference:

U.S. Fish and Wildlife Service (USFWS). 2023. Species status assessment report for the Three Forks springsnail (*Pyrgulopsis trivialis*), Version 1.0. November 2023. Phoenix, Arizona.

Table of Contents

Chapter 1. Introduction

This report summarizes the analytical phase of a Species Status Assessment (SSA) for the Three Forks springsnail (*Pyrgulopsis trivialis*). The Three Forks springsnail is a small hydrobiid snail that occurs in springs and seeps in the White Mountains in eastern Arizona. Extant populations are within the Boneyard Creek Complex (seven populations of 12 springs) or Boneyard Bog Complex (five populations of nine springs). At the Three Forks Complex, springsnails had previously occupied five springs, but those populations are now considered extirpated. In this document, when referring to the Three Forks springsnail, we use the terms "species" based on the definition in the Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 et seq.).

The SSA framework uses the three biological principles of resiliency, redundancy, and representation to assess the species' viability or its ability to persist over time (USFWS 2016, Smith et al. 2018). Within the SSA, we present a synthesis of our current understanding of the species' ecology and the factors that influence it to evaluate the current status and to predict the future status of its resources and condition. This report intends to provide biological support for a status review and recovery plan for the Three Forks springsnail; it does not represent any opinion or decision by the U.S. Fish and Wildlife Service (USFWS). Instead, the document provides a review of the best available information related to the biological status of the Three Forks springsnail.

Federal History

The Three Forks springsnail was proposed as endangered on April 12, 2011 (USFWS 2011; 76 FR 20464) and listed as a species in danger of extinction in the United States on November 17, 2012, under the ESA (USFWS 2012; 77 FR 23060). We designated critical habitat for the Three Forks springsnail in 2012 because the physical and biological features essential to the species' conservation require protection and special management conditions (USFWS 2012; 77 FR 23060).

SSA Framework

This report is a summary of the Species Status Assessment analysis, which entails three assessment stages (Figure 1):

Species Ecology. An SSA begins with a compilation of the best available biological information on the species (taxonomy, life history, and habitat) and its ecological needs at the individual, population, and species levels based on an understanding of how environmental factors act on the species and its habitat.

Current Species Condition. Next, an SSA describes the current condition of the species' habitat and demography and the probable explanations for past and ongoing changes in abundance and distribution within the species' ecological settings (i.e., areas representative of the geographic, genetic, or life-history variation across the species' range).

Future Species Condition. Lastly, an SSA forecasts the species' response to probable future scenarios of environmental conditions and conservation efforts. As a result, the SSA characterizes the species' ability to sustain populations in the wild over time (viability) based on the best scientific understanding of current and future abundance and distribution within the species' ecological settings.

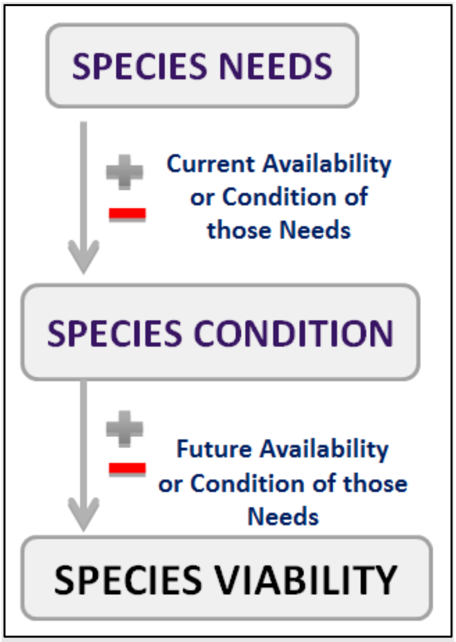

Figure 1. Species Status Assessment framework (USFWS 2016, p. 6).

Throughout the assessment, the SSA uses the conservation biology principles of resiliency, redundancy, and representation (collectively known as the "3Rs") as a lens to evaluate the current and future viability of the species. Resiliency describes the species' ability to withstand stochastic disturbance events, an ability associated with population size, growth rate, and habitat quality. Redundancy describes a species' ability to withstand catastrophic events, which is related to number of populations, species' distribution, and species' resilience. Representation describes a species' ability to adapt to changing environmental conditions and relates to the breadth of genetic and ecological diversity within and among populations. Together, the 3Rs—and their core autecological parameters of abundance, distribution, and diversity—comprise the key characteristics that contribute to a species' viability or ability to sustain populations in the wild overtime. When combined across populations, they measure the condition of the species (Smith et al. 2018 pp. 306–308).

Summary of New Information

This report uses information obtained from a variety of sources, including information from wild and captive populations of Three Forks springsnail. The main sources of new information were reports from partner agencies monitoring populations of the Three Forks springsnail.

Uncertainties and Assumptions

This report incorporates the best available information through reports, peer-reviewed literature, and communication with species experts. The use of the name "Three Forks springsnail" refers to *Pyrgulopsis trivialis*. When information is not available at the species level, we sometimes used closely related congeners (organisms belonging to the same taxonomic genus) as surrogate species but are always careful to make this clear throughout the report. For instance, some assumptions are made using the life history of the Page springsnail (*Pyrgulopsis morrisoni*), which is a springsnail also endemic to Arizona. Although deemed reasonable, we recognize this approach contains inherent uncertainties[1].

Chapter 2. Species Ecology and Needs

This chapter provides biological information about the Three Forks springsnail, including its taxonomic history and genetic relationships, morphological description, life-history traits, and individual and population habitat needs. Within this SSA, we use the term "population" to describe a spring that currently or historically supported the Three Forks springsnail.

Taxonomy

The Three Forks springsnail is a member of the genus *Pyrgulopsis* in the family Hydrobiidae. Springsnail species are relicts of the Pleistocene Epoch (2.58 million to 11,700 years ago), an era when the Southwest was much wetter (as cited in Hurt 2004 p. 1182). The Three Forks springsnail is one of approximately 170 known species of hydrobiid snails in the United States, and one of 13 described species in the genus *Pyrgulopsis* that occur in Arizona (Hurt 2004 p. 1176, Hershler et al. 2016 p. 72). The Three Forks springsnail, initially described as *Fontelicella trivialis* by Taylor (1987 pp. 30–32), was later described as *Pyrgulopsis confluentis* by Hershler and Landye (1988 pp. 32–35) from a spring-fed pond at Three Forks, Apache County, Arizona. The species was synonymized to *Pyrgulopsis trivialis* by Hershler (1994 pp. 68–69), with the synonymized common name of Black River springsnail (Hershler and Liu 2017 p. 58). We have carefully reviewed the available taxonomic information and conclude that *P. trivialis* is a valid taxon. The currently accepted classification is shown in Table 1:

Table 1. Three Forks springsnail taxonomy.

Class	***Subclass***	***Family***	***Genus***	***Species***
Gastropoda	Rissooidea	Hydrobiidae	*Pyrgulopsis*	*Pyrgulopsis trivialis*

Taxonomic research has not been conducted on all sites we consider occupied for the species. However, genetic investigations have verified Three Forks springsnails within the Three Forks and Boneyard Creek Complexes (Hurt 2004 p. 1176, Myers and Varela-Romero 2012 p. 32). No evidence of other *Pyrgulopsis* has been detected. Although genetic or morphological analyses have not been conducted for all populations, current or historically occupied, we assume all springsnails currently or historically inhabiting springs within the current range of the species are Three Forks springsnails.

[1] We made assumptions regarding Three Forks springsnail from information on the Page springsnail due to the species having the most recent species-specific information for a springsnail in the Southwest. These assumptions have inherent uncertainties for Three Forks springsnail as it is a different species (but same genus and family). We need additional species-specific information for the Three Forks springsnail to minimize these assumptions and uncertainties.

GENETICS

As a relic of the Pleistocene Epoch, the *Pyrgulopsis* genus is assumed to be resilient to disturbance and localized reductions in abundance given its persistence over geologic time. High reproductive and recruitment rates within populations and resilience to the adverse effects of genetic bottlenecking following population dips, likely contribute to population resilience (Martinez and Sorensen 2007 p. 31, USFWS 2015 p. 16). Although their natural history suggests species in *Pyrgulopsis* are resilient, they are still susceptible to some extent to effects of genetic drift and bottlenecking (Johnson 2005 pp. 2307–2308). Few species-specific genetic studies have been conducted within the genus *Pyrgulopsis*, but we assume genetic resiliency is similar among most *Pyrgulopsis* species, including the Three Forks springsnail. Studies were conducted in 2003 and 2007 that compared genetics between the Three Forks Complex to the Boneyard Bog populations (Hurt and Hedrick 2003 p. 16, 2007 p. 27). In 2012, another study resulted in the identification of a unique haplotype in springsnails found at Lopez Springs along Boneyard Creek (Myers and Varela-Romero 2012 p. 32). Results suggested that springsnail from Lopez Springs are the closest genetic neighbor (i.e., shared haplotypes) to those formerly at the Three Forks Complex and would be the preferred source population for reintroductions into extirpated sites within the Three Forks Complex (Myers and Varela-Romero 2012 p. 32). Overall, haplotypes and the genetic distances between the Lopez Springs populations and the Three Forks population sites are not known. Likewise, the genetic relatedness among populations along Boneyard Creek is unknown, because those springsnail populations are too small to take a sufficient sample size to genetically test. However, a genetic study by Lavretsky et al. (2021 pp. 3, 7) did verify Three Forks springsnail haplotypes found in several Boneyard Bog populations.

SPECIES DESCRIPTION

With adult shell height (length) ranging from 1.5 to 4.8 millimeters (mm) (0.06 to 0.19 inches (in)), the Three Forks springsnail is variable in size. More specifically, the springsnail has an ovate to narrowly conic shape and 3.5 to 5.0 whorls. The early protoconch (the top of the shell) is very weakly punctate (i.e., a few tiny holes), with the latter portion of the shell smooth or with faint spiral lines. The whorls following the protoconch are rarely shouldered and slightly to moderately convex. The aperture (central opening of the shell) connects to the body whorl. The inner lip of the aperture is complete and thin. The outer lip is slightly forward. The umbilicus is near absent. The shell of the springsnail ranges from tan to green to black, and the operculum (the plate that closes the opening of the shell when the snail retracts) is ovate and amber in color (Hershler 1994 pp. 68–69). Verification of a species occurs through examination of characteristics of reproductive organs or molecular analysis (Hershler et al. 2014 p. 2). For a more detailed description and thorough review of Arizona hydrobiid snails' morphological characteristics, see Hershler and Ponder (1998 entire) and Hershler (1994 entire).

LIFE HISTORY

The Three Forks springsnail is a narrow endemic species, meaning that the species has a restricted geographic range. Within that range, specific habitat requirements and limited dispersal abilities contribute to constraining the species. Further, Three Forks springsnail is likely univoltine (i.e., completing one generation per year) (Lysne and Koetsier 2006 p. 235, Lysne et al. 2007 pp. 649, 650, Pearson et al. 2014 p. 64).

In hydrobiids like the Three Forks springsnail, the sexes are morphologically separate with females typically larger than males. Empirical and definitive observations of Three Forks springsnail reproduction are limited. Therefore, while there is general insight into ecological conditions suitable for reproduction, species-specific information is limited, and any significant interspecific variation in ecological requirements are unknown. In general, *Pyrgulopsis* species are dioecious (i.e., separate male and female individuals), females are oviparous (egg-laying) (Hershler et al. 2014 p. 2), and reproduction appears to occur throughout the year in warm water (20-30 °Celsius, (°C)) and in most months in cooler water (11-13 °C) (Mladenka and Minshall 2001 pp. 207-209, Stevens and Poynter 2019 pp. 1-3). Because the Three Forks springsnail occurs at higher elevations, and in cooler springs (14-17 °C; Martinez and Myers 2008 p. 190) we assume that the Three Forks springsnail can reproduce during most months. However, we do not know if other environmental cues could affect breeding. These environmental cues could include photoperiod, water temperature, water quality, or food availability. Given their similar environments, we infer from the Page springsnail that the Three Forks springsnail may have a peak reproductive period from mid-August through September, which is further supported by observations of newly emerged snails (Pearson et al. 2014 p. 65) and a potential reduction in activity, which likely indicates the dying of older individuals, that starts in September.

Studies on the survival, growth, and longevity of the Three Forks springsnail have not occurred. General insights related to hydrobiids, including Page and Huachuca springsnails (*Pyrgulopsis thompsoni*), indicate that lifespan is about one year, and adults can overwinter by burrowing in sediment (Lysne and Koetsier 2006 p. 235, Lysne et al. 2007 pp. 649, 650, Pearson et al. 2014 p. 64). For most aquatic gastropods, lifespan is usually nine to 15 months (Pennak 1989 p. 552). One species in the genus *Pyrgulopsis* survived in the laboratory for nearly 13 months (Lysne et al. 2007 p. 3). However, observations from captive populations indicate that Page springsnails could live two to three years (Phoenix Zoo pers. comm. 2023). Therefore, an average lifespan of one year is a reasonable estimate for the Three Forks springsnail (Figure 2).

Completion of the larval stage for many hydrobiids occurs in an egg capsule. Once hatched, tiny snails crawl out into the habitat they will occupy for the rest of their life cycle (Brusca and Brusca 1990 p. 759, Hershler and Sada 2002 p. 256). While juvenile Three Forks springsnails have been observed in captivity at the Phoenix Zoo (Figure 3), egg laying and developmental stages have not yet been recorded. Observation of the Page springsnail laying single eggs has occurred (Figure 4), and we assume that the Three Forks springsnail also lays single eggs. Laboratory observations of the Page springsnail also showed females laying one egg approximately every eight to 10 days (Pearson et al. 2014 p. 66). We are, however, uncertain whether the Three Forks springsnail follows a similar pattern. We assume that completion of the entire larval stage would occur within the egg. Pearson *et al.* (2014 pp. 66–67) observed the development rate of Page springsnail in a laboratory setting, noting that growth was rapid during the first two weeks, but reduced as snails approached adult size. Wells *et al.* (2012 p. 73) also observed in a laboratory setting that it took six to seven weeks for a Page springsnail to reach full maturity. Given the similarities of the environment between the Page and Three Forks springsnails (dry arid climate, variable precipitation), we assume that the Three Forks springsnail develops at a similar rate.

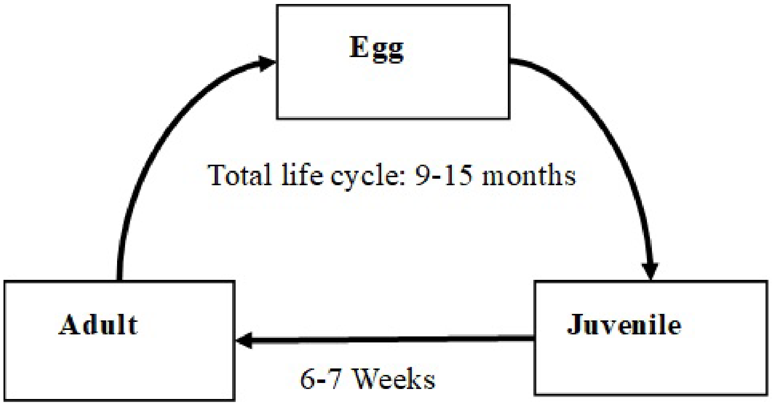

Figure 2. Life cycle of the Three Forks springsnail from egg to juvenile to adult, which all occurs within 9 to 15 months.

Figure 3. Photos depicting an adult springsnail (left) and a juvenile springsnail (right). Photos were taken by Whitney Heuring with the Phoenix Zoo while Three Forks springsnails were held there.

Figure 4. Photos depicting the single egg laid by the Page springsnail. Photo taken by Stuart Wells with the Phoenix Zoo while Page springsnails were held there.

An environment's temperature can significantly affect an organism's energy allocation, with warmer temperatures positively correlated to the metabolic rate of poikilothermic organisms (an organism whose internal temperature varies considerably) (Hammill et al. 2004 pp. 254-256). There can also be a direct relationship between temperature and an organism's mating behavior, reproduction, development, and general survival for some species. If the temperature increases, those behaviors and survival rates increase, and if temperature decreases, then those behaviors and survival rates decrease. This relationship was demonstrated in the giant ramshorn snail (*Marisa cornuarietis*), another freshwater mollusk in the Planorbidae family (Funkhouser 2014 p. 5). However, for the Phantom Cave springsnail (*Pyrgulopsis texana*), temperature did not affect reproduction or growth (Funkhouser 2014 p. 16). It is unknown if the Three Forks springsnail's life history exhibits a relationship to water temperature beyond the observed increases in activity, what would qualify as warm and cold springs within their range, or at what temperature threshold adverse effects would take place.

THREE FORKS SPRINGSNAIL NEEDS

As a species, the Three Forks springsnail needs multiple, resilient populations to maintain ecological and genetic diversity throughout its range. In turn, resilient populations need individuals that survive and successfully reproduce to maintain viable numbers. Needs for the Three Forks springsnail at the individual, population, and species levels are described below.

Individual Snail Needs

The different life stages of the Three Forks springsnail dictate the individual needs of the species (Table 2). Completion of all life stages occurs within about 3 meters (m) (10 feet (ft)) of the springhead. For the spring system to be suitable for all life stages, it should contain hard substrates, vegetation, sufficient water quality and quantity, and few or no invasive species (i.e., crayfish) or competitive species (i.e., pond snails). Eggs need sufficient water quantity (greater than 1 cm deep) to prevent desiccation (Pearson et al. 2014 pp. 65–67) and water quality that is devoid of copper, ammonia, or cyanide, but contains the calcium ions needed for shell development (Pennak 1989 p. 552, Brusca and Brusca 1990 p. 759, U.S. Forest Service (USFS) 2007 entire, Wells et al. 2012 p. 72). Adults and juveniles use hard substrates to adhere to and feed on and use vegetation (living and debris) as shelter from virile crayfish (*Orconectes virilis)*. Adults also use hard substrates, potentially even other snail’s shells, and vegetation on which to lay eggs. Every life stage is sensitive to water quality parameters, such as dissolved oxygen and contaminants. In one captive refugia population, a die-off occurred following a minute increase in environmental copper concentration (Sada 2007 p. 66, Wells et al. 2012 pp. 70–71). A stable temperature is also necessary for all life stages, as temperature influences metabolic rates, mating behavior, and body size (Funkhouser 2014 pp. 4–5).

Table 2. Life cycle needs of the Three Forks springsnail based on life stage.

	Hard Substrate	***Vegetation (Living, Debris)***	***Water Quality***	***Water Quantity (greater than 1 cm deep)***	***Absence of Invasive Crayfish***
Egg	A place to adhere to for the duration of development.	Provides a place to adhere to for development.	Allows for the successful development of eggs.	Prevents desiccation of eggs.	Prevents predation.
Juvenile	A place to feed.	Provides a source of cover and possible place for periphyton to adhere.	Allows for the survival of individuals and the growth of food.	Prevents desiccation.	Prevents predation and resource competition.
Adult	A place to feed and breed.	Provides a source of cover and possible place for periphyton to adhere.	Allows for growth and successful breeding, and growth of food.	Prevents desiccation.	Prevents predation and resource competition.

Population Needs

For this SSA's purposes, we define a population of Three Forks springsnails as those snails within a single spring. We apply this definition because dispersal between springs is rare, and each population generally functions on its own (Myers and Varela-Romero 2012 pp. 31–32). Previous studies have used the term "sites" to describe the specific springs in which springsnails occur. We use the term "population" to describe springs that are currently or historically occupied and "population-sites" for springs not known to be historically occupied but that could serve as reintroduction opportunities.

A population of Three Forks springsnails needs to have sufficient recruitment to sustain populations overtime. Research suggests that a population abundance of 500 individuals is sufficient to maintain the adaptive potential of freshwater invertebrates (Johnson et al. 2022 p. 4, Jones et al. 2012 p. 34), which we assume is applicable to freshwater springsnails. To sustain sufficient populations, invasive nonnative species (e.g., crayfish) and competitors (e.g., pond snails) must be removed or greatly reduced in number where springsnail populations exist. Also, to sustain sufficient populations, the presence of specific habitat characteristics – including hard substrates which allow for feeding, breeding, and egg laying – are needed.

Species Needs

To adapt to changing environmental conditions, the Three Forks springsnail species needs to maintain its ecological and genetic diversity (representation) in resilient populations distributed throughout the species range (redundancy and representation). Within the Three Forks springsnail's range, habitat suitability and connectivity are essential for maintaining populations and allowing for reintroductions.

HABITAT

Free-flowing springheads, concrete boxed springheads, spring runs, spring seeps, and shallow ponded water are places the Three Forks springsnail are typically found (Figure 5; Martinez and Myers 2008 p. 189). The presence of the Three Forks springsnail is associated with gravel and pebble substrates, shallow water up to 6 cm (2.4 in) deep, conductivity on average of 131.5, alkaline waters with a pH of 8, and the presence of pond snails (*Physa gyrina*) (Martinez and Myers 2008 pp. 189–194). Furthermore, the density of springsnails is greater in water depths less than 5.6 cm (2.2 in), in which the density of pond snails is less than 4.6 per square meter (5.5 per square yard), and where the distance from the springhead is less than 0.8 m (2.6 ft). Although research indicates that Three Forks springsnails exhibit higher density in shallower water, the species does not appear to be intolerant of deeper ponded water with flocculant mud, vegetation, and hard substrates (Taylor 1987 p. 32). The habitat features most important to the Three Forks springsnail, based on our understanding of its life history and ecology, include:

1) Adequately clean spring water (free from contamination as described above in Individual Needs) emerging from the ground and flowing on the surface;

2) Periphyton (attached algae), bacteria, and decaying organic material for food;

3) Substrates that include cobble, gravel, pebble, sand, silt, and aquatic vegetation, for egg-laying, maturing, feeding, and escape from predators; and

4) Either an absence of nonnative predators (e.g., crayfish) and competitors (e.g., pond snails) or their presence at low population levels.

Parameter estimates, by USFWS Science Applications, from mixed-effects hurdle model estimating number of Three Forks springsnails within springs in east-central Arizona between 2008-2020 showed that silt, hard substrate (pebble and cobble), and pH were all correlated with the presence or absence of Three Forks springsnail as shown below.

Count Model	**Estimate**	**95% Confidence Interval**	***P***
Model (Intercept)	1.77	0.57-5.55	0.326
Model Component: Aquatic Beetles	0.54	0.23-1.23	0.141
Model Component: Percent Cobble	0.66	0.48-0.90	**0.009**
Model Component: Percent Pebble	0.43	0.24-0.77	**0.005**
Model Component: Percent Silt	0.3	0.18-0.50	**<0.001**
Model Component: Physid Snails	0.43	0.20-0.93	**0.031**
Model Component: Percent Vegetation Cover	1.22	0.77-1.94	0.4
Model Component: Water Conductance	0.79	0.42-1.48	0.464
Model Component: Water pH	2.34	1.55-3.53	**<0.001**
Model Component: Water Temperature	0.89	0.51-1.53	0.664
Model Component: Overdispersion Parameter	5.02		
Zero-Inflated Model (Intercept)	1.28	0.82-1.98	0.0271

Random Effects	**Variance**
Year	0.84
Site: Spring	1.93

Results from Martinez and Rogowski (2011 p. 218) support the hypothesis that in the wild, distance from spring vents correlates with the number of Three Forks springsnails. They found that depth of water, distance from the springhead, and pH explained 36.1 percent of the variance in springsnail density. After 0.8 m (2.6 ft.) from the springhead and when water depth was greater than 5.6 cm (2.2 in.), springsnail density began declining (Martinez and Rogowski 2011 p. 218). In 2015, research by Piorkowski and Diamond on the Huachuca springsnail, found in the Huachuca Mountains of southern Arizona supported this finding; Huachuca snails were not present more than 12 m (39.4 ft.) from a spring vent (Figure 6, Piorkowski and Diamond 2015 p. 16). This study, as well as research conducted by Hershler *et al.* (2014 p.5), emphasized that habitat characterized by minimal competition and predation by invasive species benefits springsnail populations (Piorkowski and Diamond 2015 p. 17).

Figure 5. Habitat photos of both a modified springbox and natural springhead.

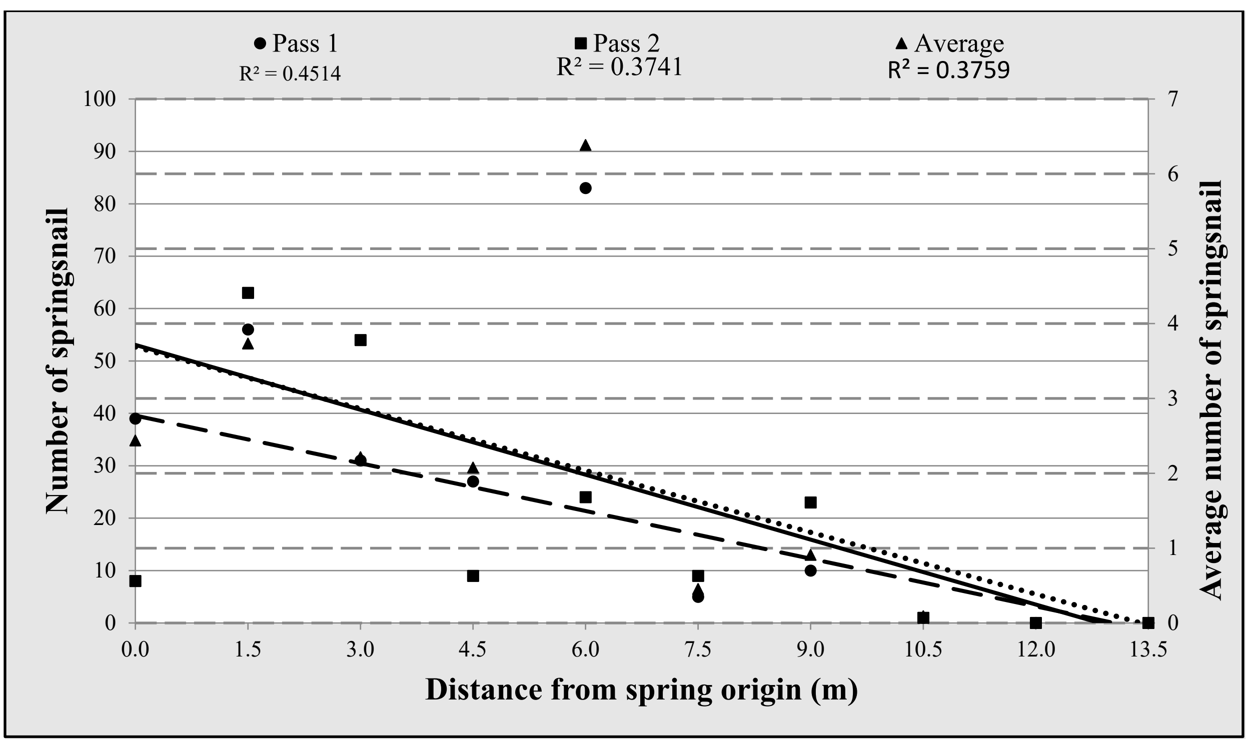

Figure 6. Comparison of Huachuca springsnail numbers by distance from the spring origin using the Tile protocol. Trendlines and associated R^2 values indicate the level of relatedness the trendline has with the

data (Piorkowski and Diamond 2015, p. 16). In regression models, R^2 values inform us on the percent of variance that is explained by the predictor variable.

MOVEMENTS AND DISPERSAL

Three Forks springsnail mobility is limited, given their small size and the low frequency for which significant dispersal events occur for this species. However, dispersal of aquatic snails has occurred when individual snails attached to the feathers of migratory birds (Roscoe 1955 p. 66, Dundee et al. 1967 pp. 89–90, Wesselingh et al. 1999 entire, van Leeuwen and van der Velde 2012 pp. 967–970), and stochastic events such as floods may assist with reintroductions and dispersal (Piorkowski and Diamond 2015 p. 27). Given the information available, we conclude that such dispersal events are infrequent and cannot be relied upon for site colonization or significant genetic flow.

Chapter 3. Range and Distribution

HISTORICAL RANGE AND DISTRIBUTION

The known historical range of the Three Forks springsnail is limited to the Three Forks Complex. The Three Forks Complex contains a series of five different springheads along the East Fork of the Black River in the White Mountains on the Apache-Sitgreaves National Forests. Although other seeps and spring features exist within the complex, some of which had springsnail presence, there is uncertainty if they historically supported populations of springsnails because of the lack of repeated survey data. Regardless, the five surveyed springheads in this area leading up to 2003 showed signs of population decline. The last documentation of the springsnail in the complex occurred in 2003. Springsnails at the complex are now considered extirpated. Although the Three Forks springsnail was not known at Boneyard Creek and Boneyard Bog Complexes until 2011 (Myers 2011 entire) and 1995 (Myers 1995a entire), respectively, it is reasonable to assume that these complexes were historically occupied because of the species' life history and limited dispersal capability. Furthermore, it is not unreasonable to consider that the historical range may have included additional sites within the North Fork East Fork Black River basin of the Gila River.

RANGE AND DISTRIBUTION

The current, historical, and potential future range of the Three Forks springsnail includes 26 populations and population-sites along Boneyard Creek and its confluence with the North Fork East Fork of the Black River in the White Mountains on Apache-Sitgreaves National Forests (Figure 7, Table 3). These populations and population-sites include springheads and seeps and can be broken up into three geographically distinct complexes including: the Three Forks Complex, the Boneyard Creek Complex, and the Boneyard Bog Complex. Each of these spring complexes occurs in shallow canyon drainages or open mountain meadows at 2,500 m (8,200 ft) in elevation. The entire potential range of the springsnail is encompassed along perennial waterways within 6 kilometers (km; 3.7 miles (mi)). Despite the Three Forks Complex being comprised of populations considered to be locally extirpated since 2003, the complex is included in the range for the reasons described below (USFWS 2012 entire, Martinez and Sorensen 2016 entire). The Boneyard Creek Complex includes extant populations at Lopez Springs, which has the closest haplotype to the extirpated Three Forks Complex haplotype. However, the Lopez

Springs populations have shown consistent signs of decline, with only one springsnail found in 2019. Below we describe each complex and the associated habitat features that are essential for the conservation of the Three Forks springsnail. Snail abundance and habitat association data used in this document are from surveys conducted using Arizona Game and Fish survey protocols (Sorensen 2022 entire).

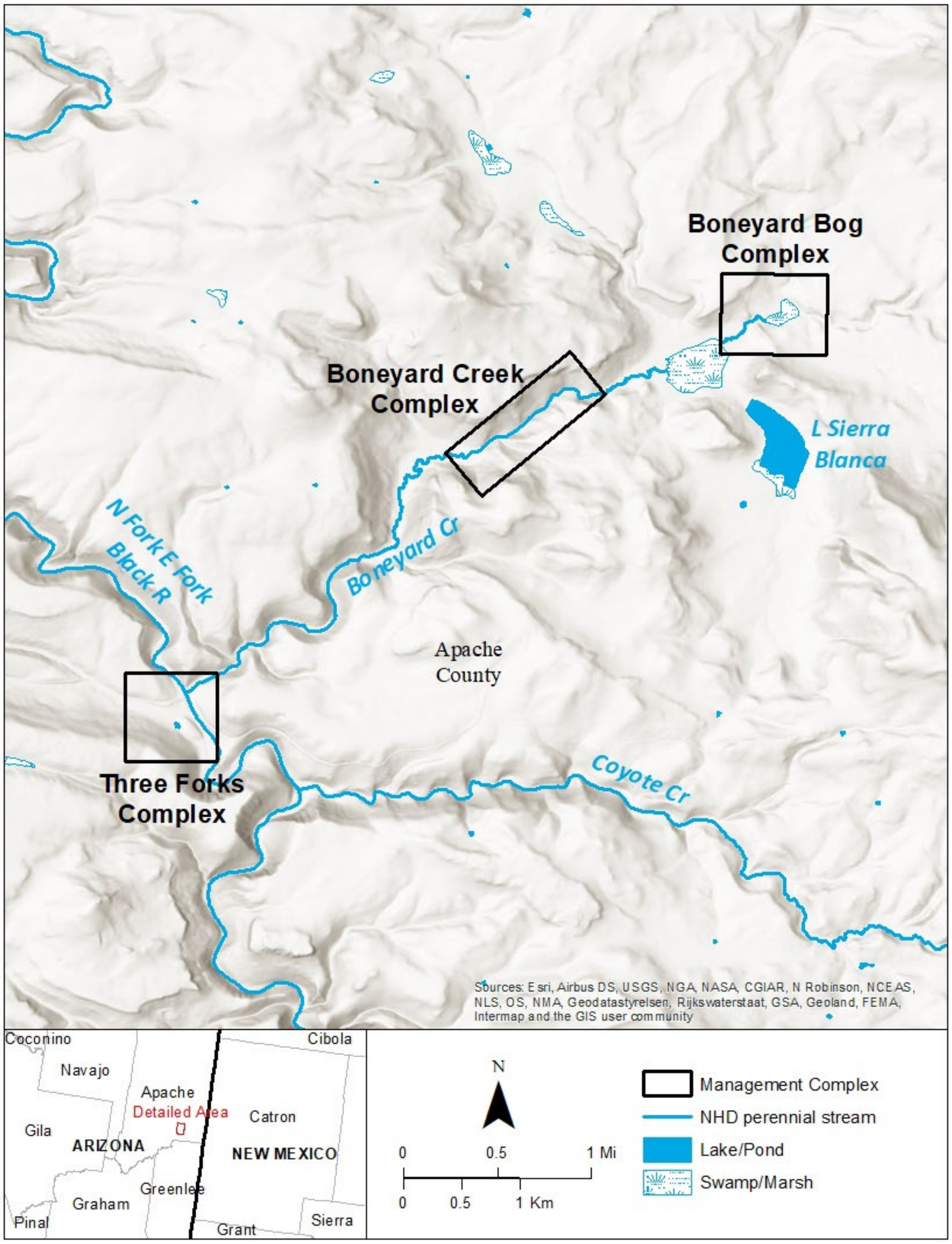

Figure 7. Locations of the Three Forks springsnail population complexes. NHD perennial streams indicates streams from the National Hydrological Database layers.

Three Forks Complex

We consider the Three Forks Complex to contain five distinct springheads. Although other seeps and spring features exist within the complex, there is uncertainty if they historically supported populations of springsnails All five springheads flow a short distance to the Black River (Figure 7). Four of the five springs have springboxes, while the fifth spring is unmodified in its natural state. The complex also includes a small amount of upland area, approximately 1.0 m (3.3 ft) in width, which encircles the springhead, runs, seeps, and Boneyard Creek, creating a contiguous area of approximately 2.5 hectare (ha; 6.1 acres (ac)) in Apache County, Arizona. The entire complex is in Federal ownership and managed by the Apache-Sitgreaves National Forests. An unnamed tributary provides habitat connectivity to other features within the complex.

The Three Forks Complex is currently unoccupied but may be suitable for future reintroductions because of ongoing habitat management in preparation for reintroductions. The Three Forks springsnail was first documented in this complex in 1973 (Landye 1973 p. 49), and the species was last documented in 2003 (Martinez and Sorensen 2016 entire). Leading up to 2003, crayfish were first found at the Three Forks Complex in 1993, and by 2000 had become established in the complex and nearby waterways (Fernandez and Rosen 1996 pp. 10–12, Myers 2000 p. 1). In 2004, it is suspected that the waters became contaminated by wildfire retardant deposition that drifted into the complex during the management of the KP-Three Forks Fire. While fire retardant becomes nontoxic within a few days of contact with water, initial contact is known to be toxic to a variety of species (Norris and Webb 1989 p. 5, Gaikowski et al. 1996 pp. 1368–1373, Little and Calfee 2002 pp. 15–22, USFS 2007 entire), and could have resulted in the local extirpation of springsnails at this complex. Currently, the Three Forks Complex contains all of the habitat features and functions to allow the springsnail to persist except for the high density of invasive crayfish.

In 2014, the Arizona Game and Fish Department with the USFS, USFWS, Nature Conservancy, Phoenix Zoo, and National Wild Turkey Foundation conducted alterations to Three Forks Springbox 2. Subsequent surveys suggest successful elimination of crayfish from this springbox. Similar alterations to the other three springboxes at Three Forks were completed in 2022 and are expected to be beneficial to the species. We consider the Three Forks Complex necessary for the conservation of the species for the following reasons: (1) it contains the specific habitat components that can support all of the Three Forks springsnail life processes; (2) the current occupied range is not sufficient for recovery; and (3) if repatriated, occupancy would increase the species' population redundancy. The primary threats in this complex are crayfish and overgrowth of vegetation in modified springboxes. Range-wide threats, such as contamination from fire retardant and drought, also exist.

Boneyard Creek Complex

The Boneyard Creek Complex consists of 12 springheads, spring runs, and spring seeps. Boneyard Creek connects all of the springs within the complex (Figure 7). The complex also includes a small amount of upland area, approximately 1.0 m (3.3 ft) in width, on each side of the springhead, runs, seeps, and the creek which creates a single, contiguous area of approximately 2.3 ha (5.8 ac), in Apache County, Arizona. The entire complex is in Federal ownership and managed by the Apache-Sitgreaves National Forests. Of the 12 springheads in the complex, eight are located along Boneyard Creek and four are located at Lopez Springs. Boneyard Creek provides habitat connectivity through surface water connections which provide a means for springsnail dispersal downstream.

The Boneyard Creek Complex, currently occupied, contains all of the habitat functions and resources essential for the persistence of the species but does contain an encroaching crayfish population.

Lopez Springs

Lopez Springs is made up of four springheads located in the western part of the Boneyard Creek Complex. These springs share the same drainage with Boneyard Creek, which provides connectivity among the four springs. We describe it separately here, however, because a 2012 genetics study found that the springsnail haplotypes at this spring are likely the closest genetic neighbor to the extirpated Three Forks Complex snails (Myers and Varela-Romero 2012 p. 32). All four springheads are comprised predominantly of pebble or cobble substrates and watercress as the dominant vegetation. Most springheads have low flow and low depth (averaging 2 cm deep).

Boneyard Bog Complex

Connected by Boneyard Creek, the Boneyard Bog Complex is comprised of nine springheads, spring runs, and spring seeps that are surveyed regularly (Figure 7). This complex also includes a small amount of upland area, approximately 1.0 m (3.3 ft) in width, on each side of the springhead, runs, seeps, and the creek which creates a contiguous area of approximately 2.3 ha (5.8 ac), in Apache County, Arizona. The entire complex is in Federal ownership and managed by the Apache-Sitgreaves National Forests. The Boneyard Bog Complex provides for springsnail movement downstream and is necessary for habitat connectivity.

Currently occupied, the Boneyard Bog Complex contains all the habitat functions and resources essential for the persistence of the species but has an encroaching crayfish population.

Table 3. Complex name with site IDs and description of the complexes. All sites occur on USFS land.

Analysis Unit Name	***Site Binomial ID***	***Site/Analysis Unit Description***
Three Forks Complex	SB1A, SB1B, SB2, SB3, NSH	Historically occupied, this complex contains suitable substrate, good water flow, and good water quality. The high density of crayfish currently makes this complex unsuitable for reintroductions without modification of the springboxes.
Boneyard Bog Complex	BYB1, BYB2A & 2B, BYB3, BYB4, BYB5A & 5B, BYB6, BYB7	Some springheads are currently occupied (BYB1, BYB2A, BYB2B, BYB4, BYB5A, and BYB7), with others considered historically occupied (BYB3, BYB5B, and BYB6) because of suitable habitat and proximity to occupied sites. Crayfish are present and could be preventing the re-establishment of populations.
Boneyard Creek Complex	PT1, PT2, PT3, PT4, PT5, PT6, PT7, PT8	Some springheads are currently occupied (PT2, PT3, PT5, and PT7), others considered historically occupied (PT1 and PT4) because of suitable habitat and proximity to occupied sites, and one (PT8) has no known historical occupancy. Spring runs in this complex are small. Crayfish are present and could be preventing the re-establishment of populations.
Lopez Springs	LS1, LS2, LS3, LS4	Two springheads (LS1 and LS3) have suitable substrates and water flow for the springsnail and two (LS2 and LS4) have less suitable substrates and lower water flow, but water quality is suitable. Crayfish are present and are believed to have precipitated the recent decline at Lopez Springs. Crayfish presence could be preventing population reestablishment. Two springheads (LS2 and LS4) have no known historical occupancy.

Chapter 4. Viability and Resiliency Factors

This chapter discusses the factors influencing the viability of the Three Forks springsnail. Viability is a result of the factors influencing resiliency of populations, and the species' redundancy and representation. We discuss these viability factors and include past and current factors that influence viability (Table 4). Please note that the term "factors" can refer to both threats and conservation measures and may have either detrimental or beneficial effects to the species.

Population Resiliency

Resiliency describes the ability of a population to withstand stochastic disturbance events. This ability is associated with the demographic capacity to adjust to habitat quality. Resilient populations rely on the same habitat resources as individuals; however, how the population demographic factor responds to the habitat resource dictates the population's resiliency (Figure 8). Demographic indicators that might indicate population resiliency relate to abundance, fecundity (the ability to produce offspring), movement, and connectivity. Because there is nearly 100 percent springsnail population turnover each year, maintaining a high abundance in each population is essential, as the number of adults determines the potential for eggs and juveniles in subsequent generations. We do not know the number of eggs produced by individual females, though a Three Forks springsnail may lay only an individual egg every few days (Pearson et al. 2014 p. 66). Despite the limited dispersal and movement capabilities of individuals, connectivity between populations and sites is a vital feature for population resiliency.

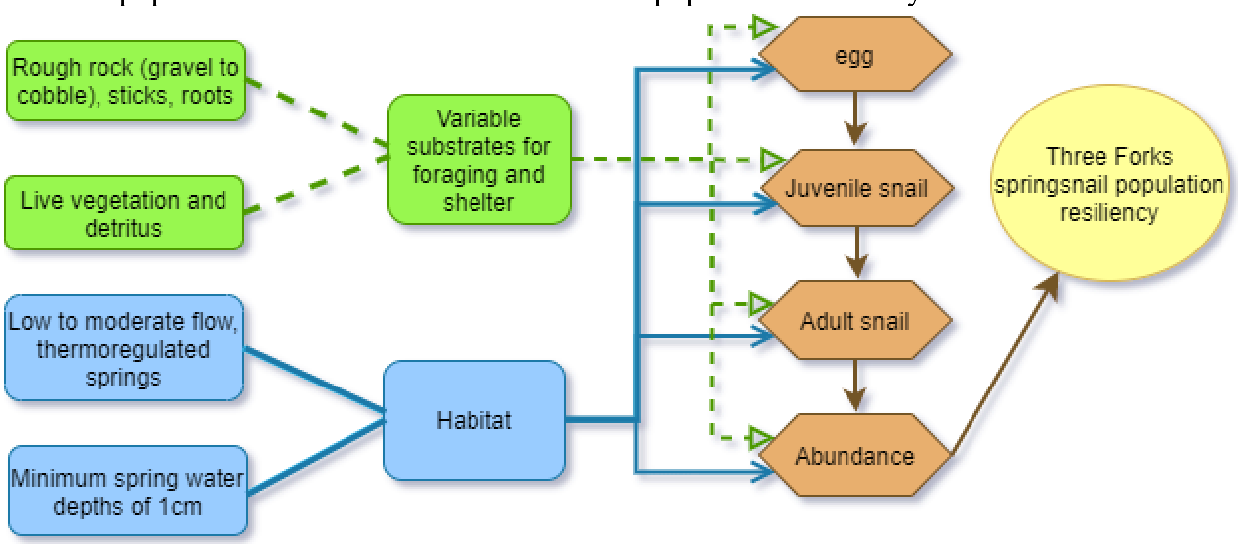

Figure 8. Conceptual model illustrating Three Forks springsnail population resiliency. Green hatched lines (hollow arrows) indicate relationships related to microhabitat needs, blue solid lines (open-line arrows) indicate relationships to macrohabitat needs.

Redundancy

Redundancy describes a species' ability to withstand catastrophic events. The number, distribution, and resilience of populations drive this ability. The extirpation of historical Three Forks springsnail populations has already reduced the redundancy of the species. Maintaining all existing populations, and reestablishing populations within the historical range, will help safeguard against catastrophic events such as high-intensity wildfires. However, with climate change increasing the potential of altered precipitation patterns and high-intensity wildfires, increasing species redundancy may not ensure the species' persistence.

REPRESENTATION

Representation describes a species' ability to adapt to changing environmental conditions through a breadth of genetic and ecological diversity within and among populations. Given the Three Forks springsnail's historical and currently narrow endemic range, ecological diversity is limited. Similarly, diminishment of genetic breadth is a concern because populations have been lost or severely decreased. Highlighting this concern are previous genetic studies that showed that springsnails at Lopez Springs have a unique haplotype; however, Lopez Springs has experienced significant population declines, with only one springsnail detected in one population in 2019 and none detected in 2020 (J. Sorensen, pers. comm. 2021). Restoration of historical genetic structure across the species range is unlikely because of such losses.

Table 4. Summary of individual, population, and species' needs for the Three Forks springsnail in terms of the 3Rs.

Level	***Need***	***Function of Need***	***Association with 3 Rs***
Individual	Hard substrates	Habitat for all life stages. Where females adhere eggs.	Resiliency
Individual	Periphyton	Provides caloric needs for juveniles and adults.	Resiliency
Individual	Living and dead vegetation	Provides shelter from crayfish and substrate for egg adhesion.	Resiliency
Individual	Water quantity	Prevents desiccation for all life stages.	Resiliency
Individual	Water quality	Correct pH, temperature, and ion concentrations are necessary for all life stages.	Resiliency
Population	High abundance	A high abundance provides greater assurance of successful recruitment and the ability to withstand changes.	Resiliency
Population	Lack of invasive species	Prevents the predation or out-competing of all life stages.	Resiliency
Population	High fecundity	Because of the short lifespan, it is necessary that fecundity and recruitment are high to replenish the population.	Resiliency
Species	Multiple, connected, resilient populations	Improves species viability by lessening the risk of extinction from catastrophic events.	Redundancy
Species	Ecological and genetic diversity within the species' range	Maintains diversity and allows for adaptability to changing environmental conditions.	Representation

Summary of Viability and Resiliency Factors

The Three Forks springsnail relies on key demographic factors, including population size, adult survival, juvenile survival, and population growth. For Three Forks springsnail populations to be resilient, populations must be large enough to withstand, and recover from, local stochastic events. This is especially important because of the limited range and short lifespan of the species. Each spring run has an unknown carrying capacity due to observable and unobservable variables such as vegetation, gradient, flow, water quality, and number of spring vents within a spring run. Because Three Forks springsnail occurrence is greater near spring vents, density of spring vents along a spring run likely influences population size and density.

Based on work and surveys done by Arizona Game and Fish Department (J. Sorensen pers. comm. 2021) and husbandry work by the Phoenix Zoo for the Huachuca springsnail (W. Heuring pers. comm. 2022), a springsnail population may need to consist of at least 200 individuals to be able to respond to small stochastic events or rebound following removal of individuals for research or management. While not a springsnail study, in 2012 a freshwater mussel study reported an effective population size is about 500 individuals (Jones et al. 2012 p. 34). A population of this size, based on modeling, would retain greater than 95 percent of molecular diversity, and prevent genetic drift (Jones et al. 2012 p. 34). Based on this information we define high condition as a population consisting of at least 500 individuals; moderate condition as 200 to 499 individuals; low condition as 51 to 199 individuals; very low condition as 1 to 50 individuals; and extirpated condition as 0 individuals (Table 6). Because of the Three Forks springsnail's small size and cryptic nature, we assume we are not detecting all snails that are present within a spring during our surveys. Thus, our counts represent only a portion of that population. We consider a population extirpated if no individuals are found after five years of similar search effort (J. Sorensen pers. comm. 2021).

Three springs were not known to be historically occupied by Three Forks springsnail but are within the historical range of the species. Habitat characteristics are surveyed at these sites, as they may be suitable for population establishment in the future. For this SSA we include them in our assessments for current and future condition as population-sites; however, their overall current condition is identified as "unknown" rather than "extirpated" given the lack of known historical occupancy.

We consider the Three Forks springsnail to be an r-selected species because of individuals' rapid development, small size, and production of multiple eggs within a short life span (Pianka 1970 p. 593, Southwood 1974 p. 797). As an r-selected species juvenile survival has the greatest influence on population growth, and therefore resilience, of a Three Forks springsnail population (Pianka 1970 p. 593, Southwood 1974 p. 797, Webb et al. 2002 p. 64). We do not know the male to female ratio needed to maintain genetic viability, hatching success, or juvenile survival at this time. We do know that springsnail hatchlings need to survive for at least 6 to 7 weeks to reach reproductive age. Upon reaching reproductive age, it is thought that adult female springsnails can lay one egg approximately every eight to 10 days (Pearson et al. 2014 p. 66), assuming there is a sufficient density of male springsnails. Based on these viability factors, the following demographic resiliency factors for populations were developed.

Demographic Resiliency Factors

Abundance

Research by Jones *et al.* (2012 p. 34) and the Phoenix Zoo, in conjunction with catch per unit effort (CPUE) trends, was used to inform our abundance demographic factor. Jones *et al*. (2012 p. 34) and work done by the Phoenix Zoo suggest that a minimum population size of 200 is needed for a mollusk population to be considered self-sustaining. Given this, annual counts (total minimum observed) over the last five surveyed years were averaged for each population. To assess population abundance, we define a high condition population as a population with at least 500 springsnails; a moderate condition population as a population with at least 200 springsnail but less than 500 springsnails; a low condition population as a population with at least 51 springsnail but less than 200 springsnail; a very low condition population as a population with less than 51 individuals; and an extirpated population as a population with no detections over the last five surveyed years of comparable survey effort (Table 6).

Three Forks springsnail abundance, however, can vary greatly year to year, and evaluation of survey count data indicated that annual population fluctuations of 100 individuals is not uncommon. To account for this, CPUE over the last five surveyed years was plotted and a linear trend line established for each population (CPUE trendline). We defined sub-brackets within the high, moderate, and low abundance condition categories to better inform the evaluation of the stability of that population (Table 5). For the abundance conditions defined above, if abundance is within the bottom 100 of the range for high or moderate, or bottom 50 of the range for low condition, and the 5-year CPUE trendline is negative, the abundance condition is considered moderate, low, or very low respectively. For example, if 549 snails are reported in a population and the 5-year CPUE trendline is negative, the abundance condition for that population is considered moderate to account for the species' natural and wide-ranging population fluctuations. For low condition, a bottom sub-bracket of 50 rather than 100 was used to be conservative when considering risk of extirpation for a population. Because an extirpated population should only be considered extirpated if no springnails persist, a sub-bracket was not defined for a population with an average abundance that falls within the definition of very low condition (Table 6). The application of sub-brackets refines our evaluation of abundance to allow for a more conservative evaluation of population abundance of the species, which is appropriate because the species is highly vulnerable to low population sizes, given the degree of annual population fluctuations observed.

Table 5. We coupled population abundance with the catch-per-unit-effort trendline to assess the abundance condition category for each population.

Abundance	***CPUE Trendline***	***Resulting Abundance Condition***
500 to 600 springsnails	Negative	Moderate
200 to 300 springsnails	Negative	Low
51 to 100 springsnails	Negative	Very Low

Determining If Augmentation Is Needed

For this SSA, we define a population as in need of augmentation if it lacks the natural recruitment needed to be considered self-sustaining. Our ability to augment a population is currently limited by reliance on wild populations as sources of individuals for translocation, because no captive population currently exists. Therefore, the actions in the following definitions do not need to be occurring for a population to meet the definition; they largely represent what is considered needed for the population and without which, the population may decline in condition or become extirpated.

We define a population in high condition as a self-sustaining population, in which natural recruitment equals or exceeds adult mortality, and no population augmentation via released captive springsnails or wild-to-wild translocations is needed. A population in moderate condition is defined as a semi-self-sustaining population in which some juvenile recruitment occurs naturally, but the population might need to be maintained during small population sizes via release of captive springsnails or wild-to-wild translocations. We define low condition as a population that is non-self-sustaining due to limited juvenile recruitment, and for which release of captive springsnails, or wild-to-wild translocations is considered necessary for viability. We define a very low population as a population without measurable juvenile recruitment and for which captive releases or wild-to-wild translocations are considered necessary for viability. Finally, we define an extirpated population as a population that requires captive releases or wild-to-wild translocations to reestablish a population at the site (Table 6). Releases or translocations of Three Forks springsnail will not occur at sites with low habitat conditions.

Habitat Resiliency Factors

For habitat resiliency factors, we consider the categories of high, moderate, low, and very low when evaluating presence of crayfish and percent of silt in a site. We do not define "extirpated" condition for crayfish or percent silt. Both habitat factors influence the abundance of Three Forks springsnails; however, the spring itself continues to persist in the presence of both crayfish and silt and we do not understand if there is a threshold of either (as measured) that alone would result in springsnail extirpation. Therefore, if some number of springsnails are documented, the lowest overall condition for the population is very low, and if no springsnails persist they are considered extirpated regardless of the condition of the habitat factors in the spring. The term "spring" includes springheads, spring runs, and seeps, regardless of occupancy.

Crayfish

The presence of crayfish, known predators of freshwater mollusks including springsnails, is a strong indicator that a spring is not currently occupied by springsnails or has experienced sharp declines in observed springsnail abundance. However, during surveys, the number of crayfish has not been reliably recorded, but crayfish presence (0) or absence (1) has been documented for each spring. Therefore, a binomial average was taken over the last five surveyed years to determine brackets of presence. A very low condition spring has greater than 0.8 as an average for crayfish being present. A low condition spring had greater than 0.4 but no more than 0.8 as an average, which indicates a high degree of crayfish being present. A moderate condition spring had from 0.2 to 0.4 average, indicating moderate degree of presence. A high condition spring had a less than 0.2 average, indicating very low presence of crayfish. Extirpated springs, in support of the findings from data, had a greater than 0.8 degree of presence and suggests that if crayfish continue to persist at an occupied spring, the springsnail population may become extirpated in the future (Table 6). Those populations and population-sites that have a low condition for crayfish would not be considered for augmentation due to the likelihood of augmentation failing due to predation.

Percent Silt

As with the presence of crayfish, the higher the percentage of silt, the less likely Three Forks springsnail would be present. This is believed to be because periphyton, the primary food source, needs hard substrates to grow on, and hard substrates are needed by springsnails to feed from, to mate, and lay eggs on. Additionally, a higher percentage of silt can make a spring more conducive to crayfish presence because crayfish are prevalent burrowers in silt; they are not as adept at burrowing in pebble or gravel (Loughman and Welsh 2013 p. 25). The virile crayfish selects habitats with low-velocity water and with depositional substrates that are made of compressed silt and detritus beds and are in areas that tend to have anthropogenic disturbances leading to elevated siltation and high nutrient loads (Loughman and Welsh 2013 p. 25). Because of this, a very low condition spring is defined as having a greater than 75 percent silt content. A low condition spring has from 51 to 75 percent silt content. A moderate condition spring has from 11 to 50 percent silt content, and a high condition spring has up to 10 percent silt content (Table 6). Those populations and population-sites that have a low condition for silt would not be considered for augmentation due to the likelihood of augmentation failing due to lack of sufficient habitat.

Table 6. Definitions of condition categories (Resiliency Factors) used to assess existing demographic and habitat parameters that influence the viability of the species.

Condition Category	***Springsnail Abundance***	***Is Augmentation Needed?***	***Crayfish Presence (binomial avg)***	***Percent Silt***
High	Greater than, or equal to 500	No. Natural recruitment equals or exceeds adult mortality, and no population augmentation via released captive springsnail or wild-to-wild translocations needed.	Less than, or equal to 0.2	Between 0 and 10 percent
Moderate	From 200 to 499	Optional. Juvenile recruitment occurs naturally, but population might need to be maintained when at small population sizes via release of captive springsnail or wild-to-wild translocations.	From 0.2 to 0.4	From 11 to 50 percent
Low	From 51 to 199	Yes. Population has limited juvenile recruitment. Captive releases and augmentation or wild-to-wild translocations are considered necessary for viability.	Greater than 0.4 to 0.8	From 51 to 75 percent
Very Low	Less than, or equal to 50	Yes. Population has no measurable juvenile recruitment. Captive releases and augmentation or wild-to-wild translocations are considered necessary for viability.	Greater than 0.8	Greater than 75 percent
Extirpated	No detection for 5 surveyed years	Yes. Augmentation via released captive springsnail or wild-to-wild translocations is needed to establish a population at the site.	NA	NA

Chapter 5. Stressors

FACTORS INFLUENCING VIABILITY

Here we consider the historical, current, and future anthropogenic or environmental factors that influence the Three Forks springsnail population resiliency, contributing to the species' overall viability. We have tried to encompass all known possible stressors that influence the Three Forks springsnail (Table 7), but we may not know all of the stressors, and novel stressors may develop over time.

Table 7. Stressors identified for the species, and our current understanding of the level at which these threats currently influence the Three Forks springsnail viability. Threats with population-level effects are discussed in more detail in this chapter.

Stressors	***Individual***	***Population***	***Species***
Drought	x	x	x
Fire	x	x	x
Flooding	x	x	
Contaminants	x	x	x
Trampling/Grazing	x	x	
Erosion	x	x	
Invasive species (mudsnail and crayfish)	x	x	x
Silt-Sand	x	x	
Flocculated silt-sand	x	x	
Small Population size		x	x
Climate change	x	x	x

In this section, we discuss the stressors at the individual, population, and species level. Currently, we do not believe there is a primary limiting factor for the Three Forks springsnail, but rather that its decline is due to small population size, encroachment of predatory crayfish, and impacts to habitat from climate change. We categorized the stressors into Overarching Stressors and Focused Stressors. Overarching Stressors, like climate change, are broad in nature and encompass a variety of other stressors, like drought. Focused stressors, like crayfish, are those stressors that directly affect a specific life stage or resource of the species. We also discuss management actions currently underway or in consideration and how these actions may alleviate some stressors. Figure 9 is an influence diagram summarizing the pathways through which management actions, and anthropogenic and environmental factors can influence the resiliency of the Three Forks springsnail by way of habitat needs or demographic parameters.

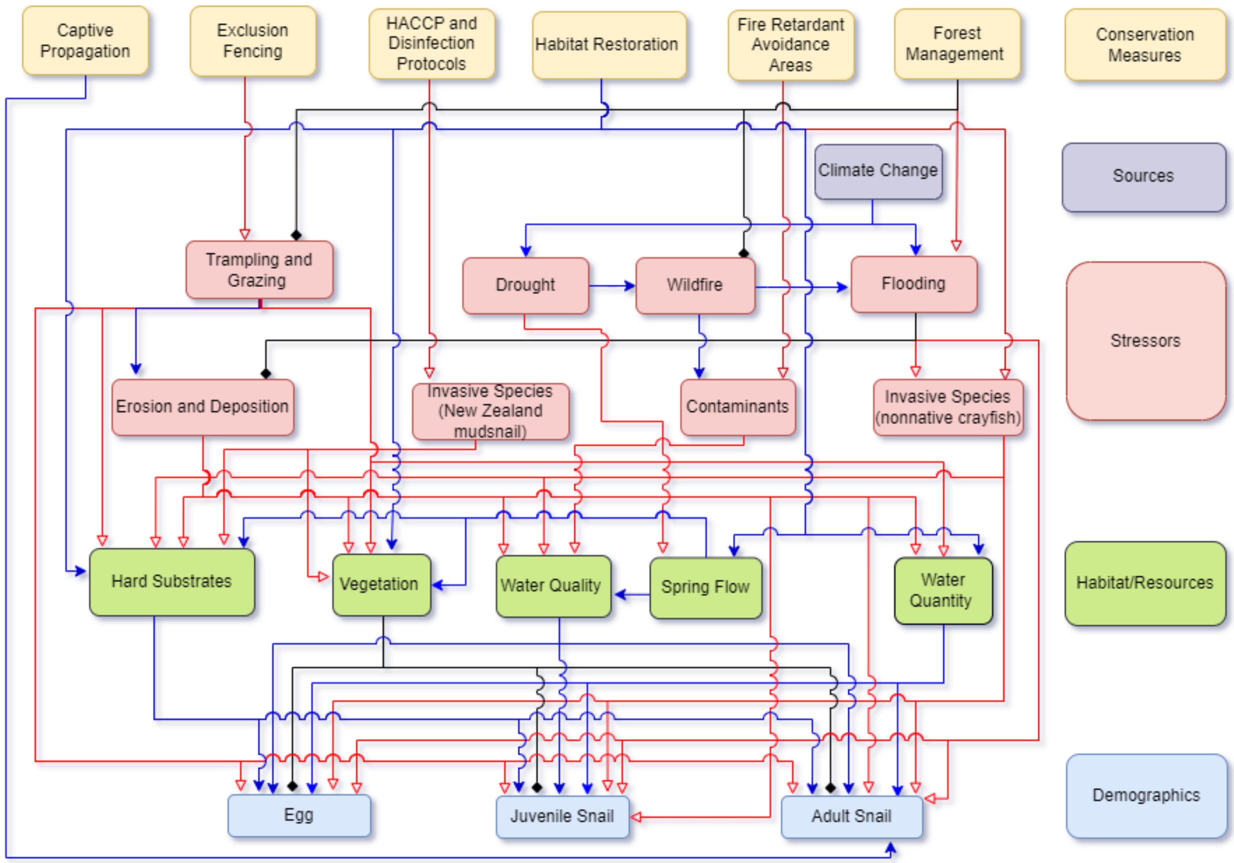

Figure 9. Influence diagram showing pathways that influence the Three Forks springsnail resiliency, by way of management actions, and anthropogenic and environmental factors. Note that arrow colors correspond to positive (blue, closed arrow), negative (red, open arrow) or either positive or negative (black, closed diamond).

Overarching Stressors

Climate change drives numerous stressors that negatively impact Three Forks springsnail habitat, thus impacting species demography and population viability. Below we discuss the stressors resulting from the source of climate change. These stressors include drought, wildfire, contaminants, flooding, and erosion and deposition. Figure 10 below provides an overview of how the source of climate change relates to these stressors, habitat/resources needed, demographics, and viability.

Drought

The National Climate Assessment indicates that the southwestern United States will continue to get hotter and drier into the future (Garfin et al. 2014 pp. 464–466, Reidmiller et al. 2018 p. 25). From 2000 to 2020, average temperatures for eastern Arizona have differed from the long-term average by an increase of 0.8 to 0.9 °C (1.4 to 1.6 °F), and the region has been abnormally dry, experiencing increased moderate to severe drought conditions (EPA 2021 entire).

The Three Forks springsnail requires spring environments that have sufficient flow volume to complete their life history. Sufficient flow removes fine grain sediments, allowing for the growth of periphyton on hard substrates and providing suitable springsnail egg-laying sites. Springs are 'recharged' from two possible sources to support discharge, the first being groundwater and the second being precipitation and snowpack melt. The Three Forks springsnail is within the Black River sub-basin of the Salt River-Highland Basin Hydrological Unit (Guenther et al. 2009 p. 137). The Black River sub-basin is comprised of volcanic rocks (basalt flows, rhyolitic ash flows, tuffs, and tuffaceous agglomerates) with depths up to or exceeding 914 m (3,000 ft) in some areas (Guenther et al. 2009 p. 8). Quantification of groundwater data for the Black River sub-basin has not occurred, but wells in this sub-basin are typically low-yielding with an average depth of 152 m (500 ft). For example, a nearby well was estimated to have yields less than 0.37 cubic meters per minute (100 gallons per minute) (Guenther et al. 2009 p. 8). Recharge of the volcanic aquifer under this sub-basin happens through precipitation infiltrating through the ground, with the highest amount of precipitation occurring in the winter and summer. Between 1961 and 1990, the average annual precipitation was 61 to 66 cm (24 to 26 in) (Guenther et al. 2009 p. 126). Avery and Soles (2003 p. 65) found that the springs within the Three Forks springsnail historical range are reliant more on precipitation and snowmelt than groundwater upwelling.

Because these springs rely on precipitation, drought could influence the species' persistence. Levels of precipitation and snowmelt are subject to variation under climate change projections (Corell 1996 pp. 18–19, Yang et al. 2022 p. 306). Recent studies have noted that there is an increase in the fraction of winter precipitation falling as rain rather than snow in the lower elevations (maximum of 2,438 m (8,000 ft.) elevation). Effects to the amount and distribution of spring runoff is likely if this trend continues at elevations of 2,438 m (8,000 ft) or higher (Guenther et al. 2009 p. 21, Hasan et al. 2020 p. 16). This will shift the streamflow to earlier in the year, resulting in a decrease in summer flows, which are already typically low. A change from snow to rain will spread the water availability more evenly throughout the year but could result in an increase in evapotranspiration and less time and water to recharge the aquifer (Longley 2017 p. 3). While it sounds counterintuitive, drought could also increase the potential for flooding (Seneviratne et al. 2012 p. 113). This is because, as evapotranspiration increases and infiltration decreases, soils become more prone to runoff, resulting in flooding events following higher precipitation events (Seneviratne et al. 2012 p. 118). Climate change models also suggest that useable water (runoff plus recharge) will decrease (Longley 2017 p. 8), over-land precipitation may decrease by 2 percent, and evapotranspiration may increase by 2 percent (Arora and Boer 2001 p. 338, Dai et al. 2018 p. 9). If precipitation and snowmelt drop to levels that cause springs to become ephemeral, then the Three Forks springsnail populations could lose resiliency or be extirpated due to desiccation. Impacts to multiple springs in one season is also possible because the entire range is within 6 km (3.7 mi), predominantly within the same drainage.

Wildfire

In the western United States, drought driven by climate change is altering natural fire regimes; wildfires are becoming more frequent, larger, and more severe (Westerling et al. 2006 pp. 940–943, Singleton et al. 2019 p. 712). In 2011, the Wallow Fire burned 88,116 ha (217,741 ac) in Arizona and New Mexico, encompassing the known range of the Three Forks springsnail. High-severity fire burned 48 percent of the dry mixed-conifer forest within the Wallow Fire perimeter, which is greater than the historical norm for this forest type and increases the potential for erosion and flooding (Roccaforte 2013 p. 13).

Moderate- to high-intensity wildfires have the potential to encompass the entire range of the Three Forks springsnail (Martinez and Sorensen 2016 p. 3) and scorch the soils, which leads to erosion, flooding, changes in water chemistry, and higher silt concentrations (Ice et al. 2004 p. 20, Parise and Cannon 2012 pp. 219, 221). Indirect effects of fire, such as erosion, flooding, and reduced water quality, are stressors on the Three Forks springsnail. Generally, undisturbed or lightly-burned forest soils have relatively high infiltration rates (Moody and Ebel 2012 p. 62). Moderate- to high-intensity wildfires, however, can reduce infiltration by exposing mineral soils to raindrop impact that can seal soil pores at the surface. This soil pore sealing occurs when soils are heated during exposure to high-intensity fire. The heat pulse into the soil from a wildfire will first drive off water occupying larger pores, which control the gravity-dominated stage of infiltration with a time scale of hours. Continued heating drives off water from smaller pores associated with the early capillary-dominated state of infiltration with a time scale of minutes. Sufficient heat can drive off all the bound water contained in inter-aggregate and intra-aggregate pores, creating hyper-dry conditions equivalent to oven-dry soils (Moody and Ebel 2012 p. 59). These hyper-dry, water-repellent soils must first rewet before water repellency is decreased sufficiently to permit capillarity and gravity-dominated infiltration; rewetting requires either that water pressure exceeds the water-entry pressure or an extremely long contact time (Moody and Ebel 2012 p. 59). Overall, soil sealing compounds water repellency and reduces evapotranspiration because of the loss of vegetation, resulting in dramatic changes in both annual and peak streamflow and likelihood of flooding (Ice et al. 2004 p. 18).

In addition to soil sealing, ash thickness affects infiltration. In a 2012 study, burned soils became virtually impenetrable because of the "perched water table" at the ash-soil interface (Ebel et al. 2012 p. 10). Ash thickness also controls infiltration by acting as a barrier that controls the initial rewetting of the soil by the diffusion-absorption process. This layer of ash, incorporated into the soil by bioturbation or removed by wind or runoff, is temporary. Post-wildfire, water quality is reduced; elevated concentrations of nutrients such as nitrogen, phosphorus, calcium, magnesium, and potassium are often observed. Over time, as soils stabilize and vegetation recovers, nutrient concentrations typically return to pre-fire levels (Ice et al. 2004 p. 18). There is also the evidence that ash, when mixed with water, creates a high-pH solution that facilitates dispersion of soil aggregates (Parise and Cannon 2012 p. 219).

Contaminants

Land management agencies use wildland fire chemical products to assist in fire suppression efforts. These products, which include suppressants and retardants, reduce fire intensity and rate of spread, decreasing risks to firefighters and property. Application of the products can be manual or through aerial drops. The application method greatly influences the area of exposure. Increased use of wildland fire chemical products is expected as wildfire frequency and intensity increase.

The USFS has approved three types of wildland fire chemical products for use: long-term fire retardants, Class A foam suppressants, and water enhancers (USFS 2007 entire, USFS accessed December 2022). Long-term fire retardants are comprised of retardant salts such as ammonium salts, which are typically industrial strength fertilizers. These retardant salts alter the way a fire burns and decreases fire intensity even after the water contained in the retardant has evaporated. Class A foam suppressants contain foaming and wetting agents, which are similar to dish soap. The combined foaming and wetting agents slow a fire's growth by enhancing water penetration into fuels. Water enhancers contain ingredients that alter the water, allowing it to cling better to vertical and smooth surfaces, increasing its effectiveness and adhesion to fuels (USFS 2007 entire, USFS accessed December 2022). Some ingredients found in fire-suppressing chemicals include ammonium phosphate, ammonium polyphosphate (sources of nitrogen and phosphorus), guar beans, xanthan gum, calcium phosphate, color pigments (red iron oxide or other dye), and other corrosion-inhibiting additives ("PHOS-CheK Environmental and Toxicology Safety" 2009). Long-term retardants and Class A foam suppressants have both been associated with negative environmental impacts. These impacts have included harming and killing vegetation, nitrate poisoning in animals, and killing fish or other aquatic organisms (Norris and Webb 1989 p. 5, Gaikowski et al. 1996 pp. 1368–1373, Little and Calfee 2002 pp. 15–22, USFS 2007 entire).

Given the potential impacts, guidelines are in place that outline avoidance areas for aerial applications and reporting and monitoring requirements (USFS 2019 pp. 11–19, 35–43). Although avoidance is preferred, direct application to waterways may be authorized (USFS 2019 p. 24) which could result in direct effects to waterways. There is also the potential that circumstances of a fire, such as the proximity to a waterway and terrain, may result in retardants entering the waterway indirectly through environmental drift or runoff. It is thought that indirect environmental drift of wildland fire chemical products used for the 2004 KP-Three Forks Fire contributed to the extirpation of the Three Forks springsnail in the Three Forks Complex (Calfee and Little 2003 p. 1525, USFWS 2012 entire).

The increasing frequency of moderate- to high-intensity fires coupled with the restricted range of the springsnail suggest that wildland fire chemical products, including both suppressants and retardants, pose a significant threat to the Three Forks springsnail.

Flooding: Erosion and Deposition

The projected impacts of climate change on precipitation, discussed in "*Drought*" above, are expected to alter the timing and type of precipitation received at elevations at or below 2,438 m (8,000 ft). This is expected to result in an increase of "flash events" that could result in increased evapotranspiration, less time and water to recharge aquifers (Longley 2017 p. 3), and potentially increased flooding because soils are unable to sufficiently absorb precipitation before runoff occurs (Seneviratne et al. 2012 pp. 113, 118). In addition to flooding resulting from potential changes in precipitation cycles, there is risk that post-fire flooding effects from erosion, when soils are hydrophobic, will be exacerbated.

Erosion, both from heavy rain events that result in flooding and from rains following a higher severity wildfire, contribute deposition of silt and sand to waterways. For aquatic species, the type of substrate available can dictate food availability, breeding habitat, and shelter from predators. Springsnails require hard substrates like pebbles and cobble and vegetation to adhere to for feeding, breeding, and egg laying. Too high a content of silt or sand limits the ability of springsnails to meet their dietary and reproductive needs. It is thought that high silt-sand concentrations may impede springsnail movement; however, applicable research has not yet occurred.

Several factors determine silt-sand content in a spring system. The primary factor is rate of spring flow. A high to moderate flow will move silt and sand down the spring run, leaving pebbles and cobbles exposed and available. A spring with low flow will allow the silt and sand to settle and accumulate, minimizing the available hard surfaces. Springsnails, including the Three Forks springsnail, are found on silt-covered surfaces, but they are typically in lower abundances. In areas where there is limited hard substrate available, springsnails have been observed laying eggs on and feeding off other snails' shells. The prevalence of this stressor is dependent on spring flow. A reduction in spring flow will result in increased silt and reduced habitat quality, which could affect an individual's ability to feed and reproduce, ultimately reducing the population's resiliency.

The change in precipitation amounts and timing, occurring in tandem with drying soils coupled with proximity of several springs to the creek bank, result in flooding and deposition posing a significant threat to the Three Forks springsnail and those higher-risk springs.

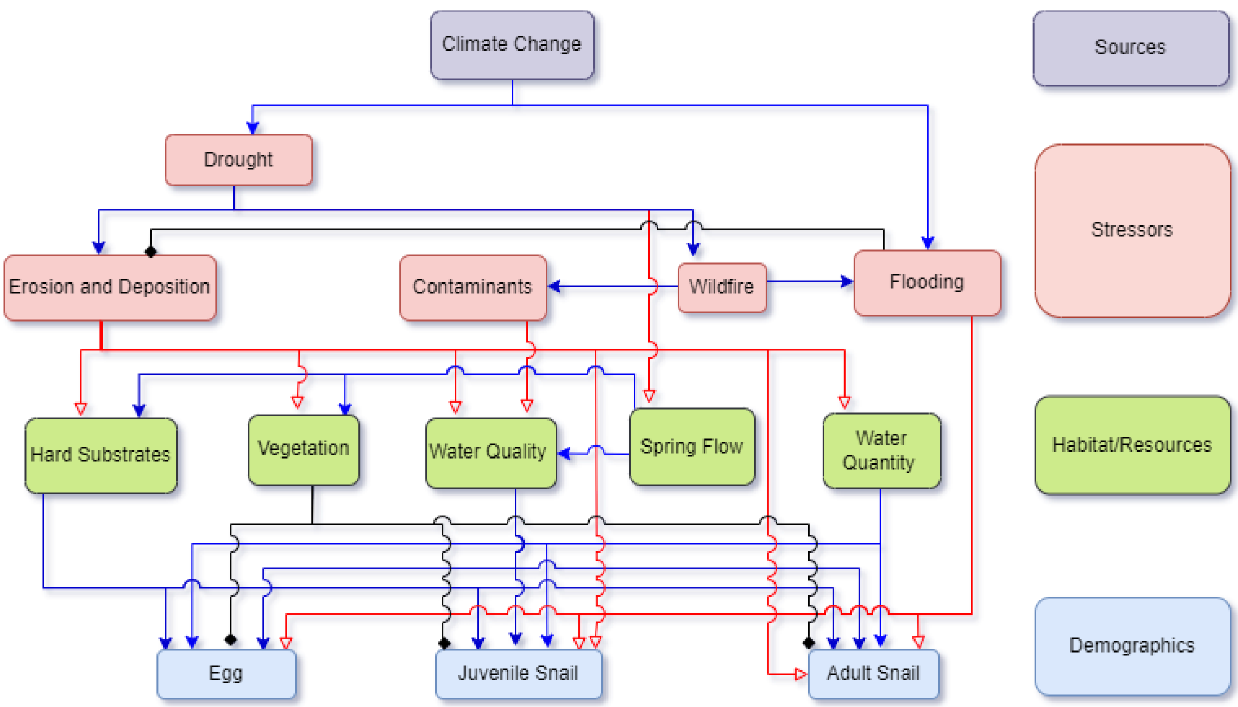

Figure 10. Influence diagram showing pathways that influence the Three Forks springsnail resiliency, specifically the overarching stressor of climate change. Note that arrow colors correspond to positive (blue, closed arrow), negative (red, open arrow), or either positive or negative (black, closed diamond) relationship.

Focused Stressors

Below we discuss focused stressors, or those stressors that directly affect a specific life stage or resource of the species. These stressors include trampling and grazing, and invasive species.

Figure 11 below provides an overview of how these focused stressors relate to habitat/resource needs, demographics, and viability.

Trampling and Grazing

Trampling and grazing from feral horses, burros, wildlife, and livestock have been described as stressors to springsnails and other spring invertebrates in various parts of Arizona and the southwest. Trampling and grazing generates sediment, can erode springhead banks and channels, and potentially causes direct mortality from crushing (Folsom and Sorensen 2018 p. 8, Pagowski and Sorensen 2018 p. 15). However, there is also concern that a lack of grazing and foraging from fencing off springheads and runs can lead to habitat degradation as vegetation becomes overgrown, which can reduce spring flow (Folsom and Sorensen 2018 p. 10). In marshy spring systems, a marked decrease in plant diversity was observed when grazing was removed, indicating that light grazing helps to maintain plant diversity (Allen-Diaz et al. 2004 p. 146). Ungrazed systems also show an impaired ability to retain nitrates due to accumulation of dead plant matter, which inhibits new plant growth (Allen-Diaz et al. 2004 pp. 146, 147).

Historically occupied sites at the Three Forks Complex are either cement springboxes or rocky substrate that are not likely to erode from occasional feral horse, elk, or deer use. Most springs and spring runs along Boneyard Creek are enclosed by elk-exclosure fencing which prevents access, and while evidence of grazing (hoof prints) have been observed in the Boneyard Bog area, impacts to the spring heads and spring runs has been limited. Conversely, lack of grazing could result in the vegetation within the enclosures becoming overgrown and inhibiting available spring flow, and periphyton growth, thus creating less suitable conditions for the springsnail. Research is needed to determine the impacts from grazing and trampling and grazing exclusions to inform management of these systems.

We do not, currently, consider stress from current grazing practices to be a significant threat for the Three Forks springsnail.

Invasive Species

Nonnative invasive species pose one of the most significant threats to flora and fauna globally, as they often outcompete and predate upon native species, have higher tolerance to disturbance, and higher reproductive capacity than native species.

Nonnative Crayfish – Nonnative crayfish reduce species diversity and destabilize food chains in riparian and aquatic ecosystems through their effect on vegetative structure and stream substrate (i.e., silt, sand, cobble, boulder) composition, and predation on eggs, larval, and adult forms of native invertebrate and vertebrate species (Fernandez and Rosen 1996 p. 3). Crayfish were first noted in the Three Forks springs system in 1993 and were considered established in the Three Forks Complex by 2000 (Myers 2000, entire). It is thought that after this establishment they began encroaching into other parts of the watershed, including Boneyard Creek and Boneyard Bog, within a few years.

Crayfish threaten the Three Fork springsnail by decreasing habitat quality and predating on all springsnail life stages (Lodge and Lorman 1987 p. 594, Hanson et al. 1990 pp. 73–77, Lodge et al. 1994 p. 1276, Sorensen 2021 pp. 13–15). By grazing on aquatic and semiaquatic vegetation, crayfish alter the abundance and structure of aquatic vegetation, which reduces cover and affects forage quality for aquatic herbivores (Lodge and Lorman 1987 p. 594, Fernandez and Rosen 1996 pp. 10–12). Filamentous algae (*Cladophora glomerata*), an important component of aquatic vegetation that provides cover and microhabitat for aquatic species, is at least 10-fold greater in aquatic habitats that lack crayfish (Creed 1994 p. 2098). Crayfish also burrow into stream banks, which increases bank erosion, stream turbidity, and siltation of stream bottoms (Fernandez and Rosen 1996 pp. 10–12). The resulting substrate conditions can result in springsnails, or other small aquatic snails, and periphyton becoming buried in the altered substrates.

Where crayfish overlap with Three Forks springsnail, crayfish populations have a noticeable influence on springsnail populations. In 1996, a controlled environment study reported crayfish consumption of all pond snails (*Physa gyrina*) and eggs within a week and a significant reduction of vegetation and other invertebrates within thirteen days; elimination of snails occurred in four out of five microcosm tanks (Fernandez and Rosen 1996 p. 25). As crayfish invade the Three Forks springsnail's range, they outcompete the springsnail for food resources and predate on the springsnail themselves. For example, abundant populations of Three Forks springsnail at Lopez Springs experienced sudden declines following initial documentation of crayfish presence (J. Sorensen AZGFD, pers. comm. 2020). Crayfish have also moved further up Boneyard Creek and are now present in Boneyard Bog. The exact year crayfish became established in Boneyard Bog is uncertain, but it is generally accepted to have been in the early 2000s.

Modifications to springboxes in the Three Forks Spring Complex have shown success in preventing crayfish establishment (Sorensen and Lerich 2015, entire). Expansion of such conservation measures may prove essential to Three Forks springsnail recovery. Erman (2002 p. 9) suggested that mechanical obstruction or removal of non-native species is needed to conserve rare and/or endemic spring species but also cautions that total eradication is usually an unobtainable objective and may cause more harm than good. Although more research is needed to fully understand the ecological relationship between crayfish and Three Forks springsnail, the best available scientific and commercial information strongly suggests that crayfish are a significant threat for the springsnail and its habitat.

New Zealand mudsnail – The New Zealand mudsnail can reach high densities very quickly, has a high tolerance to physical disturbance, and has a high invasion potential because of its parthenogenic reproductive strategy (Lysne and Koetsier 2008 p. 103, Oliver et al. 2021 p. 1). New Zealand mudsnails likely outcompete native springsnail for periphyton and exhibit faster growth rates in areas with native springsnail presence, while native springsnails exhibit slower growth rates when New Zealand mudsnails are present (Riley et al. 2008 p. 517). Currently, New Zealand mudsnails are not present within or near the range of the Three Forks springsnail. However, the potential for this non-native species to become introduced into creeks and spring runs is possible either through passive transport from birds, ingestion and deposition by fish, or deposition by ungulates or recreationalists (California Department of Fish and Wildlife accessed April 2023), as they have been detected upstream of the community of Whiteriver, approximately 60 km (36 mi) from Three Forks springsnail (USFWS 2021 p. 3).

Potential introduction of the New Zealand mudsnail by equipment is mitigated by AZGFD's equipment decontamination protocols. These protocols are in place to reduce the risk of introducing pathogens, parasites, and invasive or nuisance aquatic wildlife and plant material. For the past 20 years, AZGFD biologists have used decontamination protocols based on Hazard Analysis and Critical Control Point (HACCP) plans and equipment disinfection standards recommended by the Declining Amphibians Population Task Force Fieldwork Code of Practice.

If, however, New Zealand mudsnails are introduced into Three Forks springsnail habitat complexes, recent research suggests that it is unlikely the species would establish. This is because water in Three Forks springsnail habitat has low specific conductivity near the threshold of approximately 100 micro-Siemens/cm (µS/cm), which is known to reduce growth and fecundity of the New Zealand mudsnail (Herbst et al. 2008 entire, Larson et al. 2020 p. 114, Sorensen 2021 pp. 16–17). If New Zealand mudsnails were to become established, application of a copper-based molluscicide would be an effective eradication technique for mudsnails. However, an application has a one hundred percent mortality rate for all mollusks (native and non-native), and chronic low doses are needed to avoid impacts to fish (Oliver et al. 2021 p. 7), making this a nonviable technique without prior springsnail salvage.

The invasion of crayfish species coupled with their suspected predation on the Three Forks springsnail, and effects to their habitat, suggests that the continued presence of crayfish and their expansion across the Three Forks springsnail range poses a significant threat to the Three Forks springsnail. Conversely, mudsnails are not currently affecting the Three Forks springsnail and are not expected to do so into the future, so this stressor is not carried forward in the SSA analysis. However, effects from climate change could result in water quality becoming more suitable for the mudsnail, so mudsnails could be a potential stressor in the future.

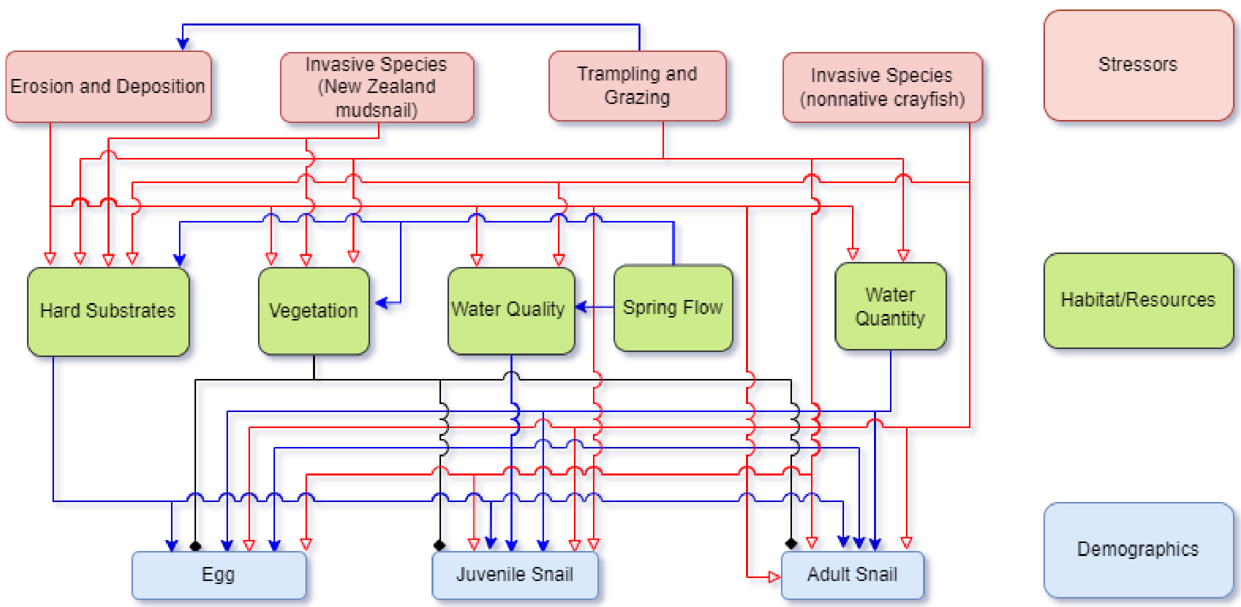

Figure 11. Influence diagram showing pathways of Focused Stressors that influence the Three Forks springsnail resiliency. Note that arrow colors correspond to positive (blue, closed arrow), negative (red, open arrow), or either positive or negative (black, closed diamond) relationship.

Other Considerations: Small Population Size

Population size typically influences the ability of a species to recuperate after a stochastic event and to be resilient to genetic bottlenecking that may result from inbreeding. In this way, a sustainable population is best described as a population with (1) the numbers that enable it to recover after an event in which individuals are lost, and (2) a genetic structure that prevents inbreeding. We do not have enough genetic information to know if we should focus on maintaining the resiliency of existing populations or focus on homogenizing populations to reestablish gene flow and extirpated populations. We recognize that maintaining genetic and ecological diversity (representation) and multiple populations distributed across the range (redundancy) is necessary for the species to adapt to changing physical and biological conditions (resiliency); however, we are concerned with the limited number of currently occupied sites, which will influence the species' overall viability. Research to understand the population size needed for sustainability over time has not occurred; however, field studies and the establishment of a captive population of Huachuca springsnail at the Phoenix Zoo indicate that a minimum of 200 springsnails is needed to either maintain or establish a self-sustaining population. This minimum estimate coupled with the endemic nature of the springsnail genus indicates that springsnails are likely inherently resistant to genetic bottlenecking and able to recover following the loss of some individuals. In a 2001 study, a USFWS biologist removed 1,776 Page springsnails from a small (less than 2.5 m^2 wet area) endemic spring over the course of four months. The population had recovered by the following year, indicating that springsnails may exhibit high fecundity and recruitment rates (Martinez and Sorensen 2007 p. 31), though the study recommended not to remove this level of a population without replacement.

Historically, multiple Three Forks springsnail populations were consistently above the minimum size of 200 individuals, with some populations reaching survey counts of over 1,000 in the early 2000s (Martinez and Sorensen 2016 pp. 13–22). However, after crayfish became present at a site, subsequent springsnail survey counts significantly dropped. Many populations are now considered small, or consistently below 200, making them more susceptible to adverse effects from crayfish presence or other stochastic events. It should be noted that because of the small and cryptic nature of the species, we recognize that surveys are likely not detecting a substantial number of springsnails, meaning that documented minimum population counts likely underestimate population size at the time of surveys.

Chapter 6. Current Conditions

This chapter analyzes the demographic and habitat conditions of the Three Forks springsnail as we currently understand them. We continue to define viability as the ability of the species to sustain respective populations over time and characterize the status of the populations in terms of its resiliency, redundancy, and representation as defined in Table 4 above.

Current Population Trends

Extant populations are within the Boneyard Creek Complex (seven populations of 12 springs) or Boneyard Bog Complex (five populations of nine springs). The Three Forks Complex is made up of five springs; however, all springsnail populations are considered extirpated.

CURRENT RESILIENCY

To minimize the impacts of disturbance to existing Three Forks springsnail populations, surveys are not conducted at specific sites annually; at most, a site might be surveyed biannually. Because of this limitation, we averaged data from the most recent five surveys conducted over no more than the last decade. Also, because population numbers fluctuate annually, averaging the last five surveyed years allows us to better understand the recent population status for the spring, whereas one year of data could be misleading, given the species' life history. For the category of "Is Augmentation Needed?" we note here that our evaluation of this condition category does not necessarily reflect current management activities. For example, for low condition where we conclude that augmentation is needed, the population is maintained entirely via release of captive springsnails and/or wild-to-wild translocations. This may indicate that translocations are currently supporting the population, or that expert opinion is that if augmentation is not conducted in the future, we are likely to lose this population to a stochastic event.

The summary of physical characteristics of each spring is not included in the methodology used in our evaluation of the demographic and habitat factors for each population or population-site, because habitat is not likely to change regarding width, depth, pH, temperature, or specific conductivity unless there is a catastrophic event. These physical characteristics are not considered in the condition analyses but are summarized for each spring, as they are helpful when comparing site suitability for augmentation. The habitat factors that inform the condition of the spring are the presence of crayfish and average percentage of silt over the last five surveyed years. This is because, after review of environmental relationships to presence of springsnail, crayfish and silt were found to be the most significant drivers of springsnail presence.

Finally, because Three Forks springsnails do not persist at extirpated sites and sites in very low condition for the abundance resiliency factor are at extreme risk of extirpation given their low population size, abundance condition is weighted differently than all other resiliency factors. For a population in "extirpated" or "very low" abundance, the overall condition of that population is described here as "extirpated" or "very low" regardless of the condition of the habitat resiliency factors.

A summary table of 34ou34ardt conditions for each population can be found in Table 8 below. Figure 12 shows the location of springheads within each complex.

Three Forks Complex

The Three Forks Complex is where the Three Forks springsnail was first documented in 1973 (Hershler 1998 entire) and where the first documented protocol survey occurred in 2002 (Martinez and Myers 2008 p. 189). In 2002, a total of 527 springsnails were found among four of five springheads, all of them within modified springboxes. Crayfish were first noted in 1993 and were considered established in the complex by 2000 (Myers 2000 entire). The last detections of the springsnail in this complex occurred in 2003 (Martinez and Sorensen 2016 p. 13, 14). It is suspected that the waters became contaminated by wildfire retardant deposition that drifted into the complex during the management of the KP-Three Forks Fire in 2004 (USFWS 2012 p. 23060, 23062, 23067). Given this, all populations in the Three Forks Complex are in extirpated condition for the demographic factors. We provide the historical average abundance of the springsnail found at each population prior to 2004. Together, these averages help provide a historical condition whilst comparing to their current overall condition.

Natural Spring Head (NSH)

The NSH is called such because all other populations in the Three Forks Complex are within springboxes constructed by the Civilian Conservation Corps (CCC), and this population remains a natural springhead. The NSH was historically occupied (Myers 2018 p. 6), however, surveys since 2002 have not detected springsnails. The cause of this extirpation is unknown and occurred prior to the KP-Three Forks Fire. Physical characteristics of this site include an average width of 0.92 m (3.0 ft.), an average depth of 6.74 cm (2.6 in.), with watercress being the dominant vegetation and silt being the most dominant substrate. In relation to water quality, the average temperature is 16.9 °C (62 °F), specific conductivity averages 121.7 μS/cm, and pH averages 8.09. The high silt content, 68 percent, places the habitat condition for silt in low condition. Additive to this low condition is that over the last five surveyed years, crayfish have been detected in five of five surveyed years resulting in a binomial average of 1.0, indicating the site is in very low condition for crayfish. With all demographic factors in extirpated condition, NSH is in an overall extirpated condition, and augmentation is needed to reestablish the population.

Springbox 1 (SB1A and SB1B)

Springbox 1 has recently been divided into SB1A and SB1B. We provide the averages of the data prior to the division because we think they are applicable to both sites. Prior to the KP-Three Forks Fire, the average springsnail population was 160 springsnails. Physical characteristics of the site include an average width of 0.97 m (3.2 ft.), an average depth of 10.92 cm (4.3 in.), with watercress being the dominant vegetation prior to the KP-Three Forks Fire. After the fire, algae became the dominate vegetation. It is unknown if a relationship between algae and crayfish exists. It is also unknown how the continued presence of this algae may influence springsnails and potential reestablishment. In relation to water quality, the average temperature is 16.9 °C (62 °F), specific conductivity averages 122.47 μS/cm, and pH averages 8.6. Pebble remains the dominant substrate, with silt comprising 2 percent, and the crayfish exclusion appears to be largely successful, indicating that these populations are in moderate condition for crayfish and high condition for percent silt. However, because abundance is in extirpated condition, SB1A and SB1B remain in an overall extirpated condition, and augmentation is needed to reestablish populations.

Springbox 2 (SB2)

Springbox 2's population, prior to the KP-Three Forks Fire, averaged 10 springsnails. Physical characteristics of this site include an average width of 0.96 m (3.1 ft.), an average depth of 18.97 cm (7.5 in.), with watercress being the dominant vegetation prior to the KP-Three Forks Fire. In relation to water quality, the average temperature is 18.97 °C (66.1 °F), specific conductivity averages 124.35 μS/cm, and pH averages 8.72. Pebble was, and still is, the dominant substrate, with silt comprising 5 percent. Crayfish have been detected in two of five surveyed years resulting in a binomial average of 0.4. Thus, SB2 is in moderate condition for crayfish and high condition for percent silt. However, with abundance in extirpated condition, SB2 is in an overall extirpated condition, and augmentation is needed to reestablish the population.

Springbox 3 (SB3)

The Springbox 3 population has had an average springsnail population of zero, even prior to the KP-Three Forks Fire. Physical characteristics of this site include an average width of 2.18 m (7.15 ft.), an average depth of 7.02 cm (2.7 in.), with watercress being the dominant vegetation. In relation to water quality, the average temperature is 17.62 °C (63.7 °F), specific conductivity averages 114.05 µS/cm, and pH averages 8.41. Pebble is the dominant substrate, with silt comprising 2 percent, resulting in a high condition for percent silt. However, SB3 is in very low condition for crayfish; over the last five surveyed years, crayfish have been detected in five of five surveyed years resulting in a binomial average of 1.0. With abundance in extirpated condition, SB3 is in an overall extirpated condition, and augmentation is needed to reestablish the populations.

Currently, SB1A, SB1B, and SB2 have been altered to prevent crayfish establishment. The alterations, including placement of fine wire meshing and small gravel to create shallow water and prevent hiding spots for crayfish, have shown to be largely successful at excluding crayfish. Alterations were also made to SB3, but these alternations, which included installment of cement board around the perimeter of the springbox to exclude crayfish, have not been successful. The continued presence of crayfish in SB3 is believed to be due to raccoon damage to the wire-mesh placed to allow water out-flow, and possibly some undetected gaps between the springbox and cement boards. Aside from crayfish, the habitat within modified springboxes appears to be good in all of the Three Forks springs, with each having a mix of pebble and rocks except for NSH which is in low condition for percent silt. Sites SB1A, SB1B, and SB2 have outflows that also have a mix of silt and vegetation, and within SB3 there is currently a mix of some boulders and vegetation. Data indicate that water quality parameters are consistent with the species' needs. Because of the habitat available, successful crayfish exclusion through springbox alterations, and planned projects to help address crayfish occupancy in the other springboxes, repatriated springsnail populations in the Three Forks Complex can likely return to a more stable and moderate, if not high, resiliency after reintroductions.

Boneyard Creek Complex

The Boneyard Creek Complex is the complex closest to the Three Forks Complex. Springsnail presence was first documented along Boneyard Creek at Lopez Springs' westernmost spring run (Lopez Spring 1) in 2010, and at the easternmost spring (PT1) in 2011 (Myers 2011 entire). The entire Boneyard Creek Complex is made up of 12 springheads, nine of which are known to have been historically occupied (Myers 2011 entire). In 2012, four of the 12 springheads were occupied by a total of 216 springsnails. In 2020, two of the 12 springheads were occupied by a total of 35 springsnails among the two springs. This is a 50 percent reduction in occupied sites, and an 83.8 percent decrease in counted snails over nine years. All 12 of the springheads are natural with unmodified hydrology, and measured habitat parameters have remained consistent. Therefore, it is hypothesized that the establishment of crayfish is likely influencing these declines.

PT1

Physical characteristics of PT1 include an average width of 1.64 m (5.4 ft.), an average depth of 1.86 cm (0.73 in.), with watercress being the dominant vegetation and pebble being the dominant substrate. In relation to water quality, the average temperature is 14.52 °C (58.1 °F), specific conductivity averages 146.5 µS/cm, and pH averages 8.67. There have been no detections of Three Forks springsnail at PT1 over the last five surveyed years; therefore, PT1 is in extirpated condition for all demographic factors. PT1 is in high condition for silt, which comprises less than 1 percent of substrates. Over the last five surveyed years, crayfish have been detected in one of five surveyed years resulting in a binomial average of 0.2, placing PT1 in moderate condition for crayfish. Overall, PT1 is in an extirpated condition, and augmentation is needed to reestablish the population.

PT2

Physical characteristics of this site include an average width of 0.61 m (2 ft.), an average depth of 2.08 cm (0.81 in.), with watercress being the dominant vegetation and pebble being the dominant substrate. In relation to water quality, the average temperature is 17.75 °C (63.9 °F), specific conductivity averages 138.87 µS/cm, and pH averages 8.21. Over the last five surveyed years there has been an average count of 21 springsnails, which puts PT2 into very low condition for abundance. The CPUE trend line is negative, so while that does not influence the condition, it reaffirms that this population is having limited to non-measurable recruitment. PT2 is in very low condition for augmentation because augmentation is considered needed to maintain the population. Substrates are comprised of 23 percent silt, placing PT2 in moderate condition for percent silt. Finally, over the last five surveyed years, crayfish have been detected in one of four surveyed years resulting in a binomial average of 0.25, placing PT2 in moderate condition for crayfish. Regardless of the moderate condition habitat parameters, we consider PT2 to be in very low overall condition.

PT3

Physical characteristics of this site include an average width of 1.07 m (3.5 ft.), an average depth of 1.6 cm (0.63 in.), with watercress and "other" being the dominant vegetation types, and pebble being the dominant substrate. In relation to water quality, the average temperature is 17.14 °C (62.85 °F), specific conductivity averages 135.57 µS/cm, and pH averages 8.37. Over the last five surveyed years there has been an average count of two springsnails, which puts PT3 into very low condition for abundance. The CPUE trend line is negative, so while that does not influence the condition, it reaffirms that this population is having limited to non-measurable recruitment. PT3 is in very low condition for augmentation because augmentation is considered needed to maintain the population. Substrates are comprised of 2 percent silt, placing PT3 in high condition for percent silt. In addition to this, over the last five surveyed years crayfish have been detected in zero of five surveyed years resulting in a binomial average of 0.0, placing PT3 in high condition for crayfish. Regardless of these high habitat parameters, we consider PT3 to be in very low overall condition.

PT4

Physical characteristics of this site include an average width of 0.68 m (2.23 ft.), an average depth of 4.03 cm (1.58 in.), with watercress being the dominant vegetation and silt being the dominant substrate. In relation to water quality, the average temperature is 16.5 °C (61.7 °F), specific conductivity averages 153.71 µS/cm, and pH averages 7.71. There have been no detections of Three Forks springsnail at PT4 over the last five surveyed years; therefore, PT4 is in extirpated condition for all demographic factors. Substrates are comprised of 43 percent silt; however, over the last five surveyed years, crayfish have been detected in three of five surveyed years resulting in a binomial average of 0.6. Thus, PT4 is in moderate condition for percent silt and low condition for crayfish. With abundance in extirpated condition, PT4 is in an overall extirpated condition, and augmentation is needed to reestablish the population.

PT5

Physical characteristics of this site include an average width of 1.22 m (4.0 ft.), an average depth of 2.08 cm (0.82 in.), with watercress being the dominant vegetation and pebble being the dominant substrate. In relation to water quality, the average temperature is 16.13 °C (61.34 °F), specific conductivity averages 130.75 µS/cm, and pH averages 7.88. Over the last five surveyed years there has been an average count of five springsnails, which puts PT5 into very low condition for abundance. The CPUE trend line is positive, so while that does not influence the condition, it could indicate limited to non-measurable recruitment. PT5 is in low condition for augmentation because augmentation is considered needed to maintain the population. Substrates are comprised of less than 1 percent silt, placing PT5 in high condition for percent silt. However, over the last five surveyed years, crayfish have been detected in three of five surveyed years resulting in a binomial average of 0.6, placing PT5 in low condition for crayfish. Overall, we consider PT5 to be in very low overall condition.

PT6

Physical characteristics of this site include an average width of 1.03 m (3.38 ft.), an average depth of 2.89 cm (1.13 in.), with watercress being the dominant vegetation and pebble being the dominant substrate. In relation to water quality, the average temperature is 16.64 °C (61.95 °F), specific conductivity averages 137.55 µS/cm, and pH averages 8.17. There have been no detections of Three Forks springsnail at PT6 over the last five surveyed years; therefore, PT6 is in extirpated condition for all demographic factors. Substrates are comprised of 5 percent silt, placing PT6 in high condition for percent silt. Over the last five surveyed years, no crayfish have been detected resulting in a binomial average of 0.0, placing PT6 in high condition for crayfish. Although both habitat factors are in high condition, PT6 is in an overall extirpated condition, and augmentation is needed to reestablish the population.

PT7

Physical characteristics of this site include an average width of 0.88 m (2.89 ft.), an average depth of 1.92 cm (0.75 in.), with watercress being the dominant vegetation and pebble being the dominant substrate. In relation to water quality, the average temperature is 16.51 °C (61.72 °F), specific conductivity averages 131.44 µS/cm, and pH averages 8.37. Over the last five surveyed years there has been an average count of one springsnail, which puts PT7 into very low condition for abundance. Because three springsnails were detected in 2020, this results in an overall positive CPUE trend line; however, there have been zero detections during the previous four of five surveys. While this trendline does not influence the condition, it could indicate that this population is having limited but non-measurable recruitment. Regardless, it is this very low abundance that results in the augmentation category being considered low because augmentation is needed to maintain the population. Over the last five surveyed years, silt has comprised 2 percent of substrates and crayfish have been detected in three of five surveyed years resulting in a binomial average of 0.6. Thus, PT7 is in high condition for percent silt and low condition for crayfish. Due to the low abundance estimates, PT7 is considered to be in overall very low condition.

PT8 Spring

Three Forks springsnail were not historically documented at PT8; however, the springhead is within the historical range of the species within the Boneyard Creek Complex. Habitat surveys began in 2017 to assess its potential for future introductions of Three Forks springsnail. Physical characteristics of this site include an average width of 0.90 m (2.95 ft.), an average depth of 1 cm (0.39 in.), with watercress being the dominant vegetation type and silt being between 0 and 25 percent. In relation to water quality, the average temperature is 15.8 °C (60.44 °F), specific conductivity averages 146 µS/cm, and pH averages 8.51. No crayfish have been detected. Overall, PT8 appears to contain all of the habitat attributes thought necessary for Three Forks springsnail persistence but is considered to be in an overall unknown condition given its lack of known historical occupancy at the site.

Lopez Spring 1 (LS1)

Physical characteristics of this site include an average width of 2.67 m (8.76 ft.), an average depth of 1.87 cm (0.74 in.), with watercress being the dominant vegetation and pebble being the dominant substrate. In relation to water quality, the average temperature is 16.94 °C (62.49 °F), specific conductivity averages 135.88 µS/cm, and pH averages 8.67. Over the last five surveyed years there has been an average count of 45 springsnails, which puts LS1 into very low condition for abundance. The CPUE trend line is negative, so while that does not influence the condition, it reaffirms that this population-site is having limited to non-measurable recruitment. LS1 is in very low condition for augmentation because augmentation is considered needed to maintain the population. Over the last five surveyed years, silt has comprised less than 1 percent of substrates, and crayfish have been detected in five of five surveyed years resulting in a binomial average of 1.0. Thus, LS1 is in high condition for percent silt and very low condition for crayfish. Overall, LS1 is in very low condition.

Lopez Spring 2 (LS2)

Three Forks springsnails were not historically documented at LS2; however, the springhead is within the historical range of the species within the Boneyard Creek Complex and has been surveyed since its discovery in 2011. The site contains habitat attributes thought necessary for Three Forks springsnail persistence. Physical characteristics of this site include an average width of 0.54 m (1.77 ft.), an average depth of 1.58 cm (0.62 in.), with watercress being the dominant vegetation and pebble being the dominant substrate, with silt closely following in average percentage. In relation to water quality, the average temperature is 18.91 °C (66.04 °F), specific conductivity averages 134.5 µS/cm, and pH averages 7.72. Over the last four surveyed years, silt has comprised 22 percent of substrates, and crayfish have been detected in four of four years resulting in a binomial average of 1.0. Thus, LS2 is in moderate condition for percent silt and very low condition for crayfish. Overall, LS2 is in unknown condition given the lack of known historical occupancy at the site.

Lopez Spring 3 (LS3)

Physical characteristics of this site include an average width of 0.47 m (1.54 ft.), an average depth of 1.57 cm (0.62 in.), with watercress being the dominant vegetation and silt being the dominant substrate. In relation to water quality, the average temperature is 18.01 °C (64.42 °F), specific conductivity averages 159.99 µS/cm, and pH averages 7.38. Over the last five surveyed years there has been an average count of 24 springsnails, which puts LS3 into very low condition for abundance. The CPUE trend line is negative, so while that does not influence the condition, it reaffirms that this population-site is having limited to non-measurable recruitment. LS3 is in very low condition for the augmentation category because augmentation is considered needed to maintain the population. Over the last five surveyed years, silt has comprised 52 percent of substrates, and crayfish have been detected in four of five surveyed years resulting in a binomial average of 0.8. Thus, LS3 is in low condition for percent silt and very low condition for crayfish. We therefore consider LS3 to be in an overall very low condition.

Lopez Spring 4 (LS4)

Three Forks springsnails were not historically documented at LS4; however, the springhead is within the historical range of the species within the Boneyard Creek Complex and has been surveyed since its discovery in 2011. The springhead contains habitat attributes thought necessary for Three Forks springsnail persistence. Physical characteristics of this site include an average width of 0.56 m (1.84 ft.), an average depth of 3.33 cm (1.31 in.), with watercress being the dominant vegetation and silt being the dominant substrate. In relation to water quality, the average temperature is 18.61 °C (65.5 °F), specific conductivity averages 146.44 µS/cm, and pH averages 7.86. Interestingly, despite proximity to the other springheads at Lopez Springs, over the last four surveyed years, crayfish have been detected in zero of four years resulting in a binomial average of 0.0, placing LS4 in high condition for crayfish. Silt, however, comprises 77 percent of substrates placing LS4 in very low condition for percent silt. Overall, LS4 is in unknown condition given the lack of known historical occupancy at the site.

Boneyard Bog Complex

The Boneyard Bog Complex is the complex located highest in the watershed. Springsnail presence was first documented in Boneyard Bog in 1995 (Myers 1995a, 1995b, Hershler 1995). The entire Boneyard Bog Complex is made up of seven springheads, two of which were split into sub-springheads. Of the overall seven springheads, five are considered currently occupied and have a summed average total of 937 springsnails. These five populations have remained relatively consistent throughout the survey periods, but the encroachment of crayfish continues to be observed and is a concern for these populations, especially those with lower abundances.

All seven of the springheads are natural with unmodified hydrology, and measured habitat parameters have remained consistent.

Boneyard Bog 1 (BYB1)

Physical characteristics of this site include an average width of 0.74 m (2.43 ft.), an average depth of 3.19 cm (1.26 in.), with watercress being the dominant vegetation and pebble being the dominant substrate, with silt closely following in average percentage. In relation to water quality, the average temperature is 15.46 °C (59.83 °F), specific conductivity averages 149.85 µS/cm, and pH averages 7.89. Over the last five surveyed years there has been an average count of 331 springsnails, which puts BYB1 into moderate condition for abundance. The CPUE trendline is positive, does not influence the abundance condition, but indicates that natural recruitment is likely exceeding adult mortality. BYB1 is in high condition for augmentation because natural recruitment is occurring, and population augmentation via released captive springsnails or wild-to-wild translocations is not needed to maintain this population. Over the last five surveyed years, silt has comprised 19 percent of substrates, and crayfish have been detected in zero of five surveyed years resulting in a binomial average of 0.0, placing BYB1 in moderate condition for percent silt and high condition for crayfish. We consider BYB1 to be in an overall moderate condition.

Boneyard Bog 2 (BYB2)

BYB2 was recently split into Boneyard Bog 2A (BYB2A) and Boneyard Bog 2B (BYB2B) to improve data collection at the springheads. The habitat data we currently have is primarily from BYB2B. Because of the proximity of the two springs and undocumented but observed similarities, we provide the physical and water chemistry characteristics here to represent both BYB2A and BYB2B. The demographic data we present, though, is summarized independently for BYB2A and BYB2B below. Physically, the two springs making up BYB2 average 0.79 m (2.59 ft.) in width, an average depth of 3.41 cm (1.34 in.), with watercress being the dominant vegetation and silt being the dominant substrate, with boulder closely following in average percentage. In relation to water quality, the average temperature is 15.51 °C (59.92 °F), specific conductivity averages 157.34 µS/cm, and pH averages 7.90. Over the last five surveyed years, silt has comprised 57 percent of substrates in BYB2B (observations suggest BYB2A has a similar distribution of substrates), and in BYB2B crayfish have been detected in four of five surveyed years resulting in a binomial average of 0.8. Given BYB2B proximity to BYB2A, crayfish can easily access both springs for feeding. Therefore, we consider both BYB2A and BYB2B in low condition for silt and very low condition for crayfish.

BYB2A

Over the last five surveyed years there has been an average count of three springsnails, which puts BYB2A into very low condition for abundance. The CPUE trend line is negative, so while that does not influence the condition, it reaffirms that this population is having limited to non-measurable recruitment. BYB2A is in very low condition for augmentation because augmentation is considered needed to maintain the population. With this demographic information, and assumed habitat information, BYB2A is in an overall very low condition, with a high likelihood of becoming extirpated.

BYB2B

Over the last five surveyed years there has been an average count of 10 springsnails, which puts BYB2B into very low condition for abundance. The CPUE trend line is positive, does not influence the abundance condition, and indicates limited or non-measurable recruitment. Regardless, augmentation is in very low condition because augmentation is considered needed to maintain the population. Combined with the habitat information available, BYB2B is in an overall very low condition.

Boneyard Bog 3 (BYB3)

Physical characteristics of this spring include an average width of 1.12 m (3.67 ft.), an average depth of 3.47 cm (1.36 in.), with watercress being the dominant vegetation and pebble being the dominant substrate, with silt closely following in average percentage. In relation to water quality, the average temperature is 16.74 °C (62.13 °F), specific conductivity averages 131.14 µS/cm, and pH averages 8.25. There have been no detections of Three Forks springsnail at BYB3 over the last five surveyed years; therefore, BYB3 is in extirpated condition for all demographic factors. Over the last five surveyed years, silt has comprised 8 percent of substrates, and crayfish have been detected in three of five surveyed years resulting in a binomial average of 0.6. Thus, BYB3 in is in high condition for percent silt and low condition for crayfish. Given that abundance is in extirpated condition, BYB3 is in an overall extirpated condition, and augmentation is needed to reestablish the population.

Boneyard Bog 4 (BYB4)

Physical characteristics of this spring include an average width of 0.69 m (2.26 ft.), an average depth of 4.05 cm (1.59 in.), with watercress being the dominant vegetation and pebble being the dominant substrate. In relation to water quality, the average temperature is 15.8 °C (60.44 °F), specific conductivity averages 148.32 µS/cm, and pH averages 8.17. Over the last five surveyed years there has been an average count of 70.6 springsnails, placing BYB4 in low condition for abundance. The CPUE trend line is positive, so while this does not influence the abundance condition, it indicates that limited recruitment is likely occurring. Regardless, augmentation is in low condition because augmentation is considered needed to maintain the population. Over the last five surveyed years, silt has comprised 2 percent of substrates, and crayfish have been detected in two of five surveyed years resulting in a binomial average of 0.4. Thus, BYB4 is in high condition for percent silt and in moderate condition for crayfish. These parameters put BYB4 in an overall moderate condition; however, because of the continued presence of crayfish, which is not likely to be abated without active management, and the low springsnail abundance, we consider this population to be in a low-moderate overall condition.

Boneyard Bog 5

Boneyard Bog 5 is comprised of two springs and the confluence of the spring runs. Over the course of surveys, Boneyard Bog 5 was recently (2017) split into Boneyard Bog 5A (BYB5A) and Boneyard Bog 5B (BYB5B). BYB5A is comprised of the springhead and the confluence where springsnails were detected. BYB5B is comprised of the other springhead. Because of the proximity of the two springs and undocumented but observed similarities, we provide the physical and water chemistry characteristics here to represent both BYB5A and BYB5B. The demographic data are summarized independently below. Physically, the springs average 0.67 m (1.19 ft.), are an average depth of 6.75 cm (2.66 in), with watercress being the dominant vegetation and silt being the dominant substrate, with pebble closely following in average percentage. In relation to water quality, the average temperature is 15.66 °C (60.19 °F), specific conductivity averages 155.40 µS/cm, and pH averages 8.04. The average silt content is lower at the confluence (8 percent), and crayfish were detected in one of two surveyed years resulting in a binomial average of 0.5, placing BYB5A in high condition for percent silt and low condition for crayfish. Given their proximity and similarities we consider both BYB5A and BYB5B in high condition for silt and low condition for crayfish because crayfish can easily access both populations for feeding.

BYB5A

Over the last five years, BYB5A has been surveyed three times with an average count of 16 springsnails, which puts BYB5A into very low condition for abundance. The CPUE trend line is negative, so while that does not influence the abundance condition, it reaffirms that this population is having limited to non-measurable recruitment. Augmentation is in very low condition because augmentation is considered needed to maintain the population. Over the last five surveyed years, the average silt percentage is 8 percent or high condition. Given this information, BYB5A is in an overall very low condition.

BYB5B

Of the four surveys done, there have been no detections of Three Forks springsnail at BYB5B; therefore, BYB5B is in extirpated condition for all demographic factors. Given that abundance is in extirpated condition, BYB5B is in an overall extirpated condition, and augmentation is needed to reestablish the population.

Boneyard Bog 6 (BYB6)

Physical characteristics of this spring include an average width of 0.65 m (2.13 ft), an average depth of 10.67 cm (4.2 in.), with watercress being the dominant vegetation and silt being the dominant substrate. In relation to water quality, the average temperature is 16.38 °C (61.48 °F), specific conductivity averages 146.88 µS/cm, and pH averages 7.83. There have been no detections of Three Forks springsnail at BYB6 over the last five surveyed years, therefore, BYB6 is43ou43rpated condition for all demographic factors. Over the last five surveyed years, silt has comprised 95 percent of substrates, and crayfish have been detected in only one of five surveyed years resulting in a binomial average of 0.2. Thus, BYB6 is in very low condition for percent silt and in moderate condition for crayfish. Given that abundance is in extirpated condition, BYB6 is in an overall extirpated condition, and augmentation is needed to reestablish the population.

Boneyard Bog 7 (BYB7)

Physical characteristics of this spring include an average width of 1.15 m (3.77 ft.), an average depth of 3.41 cm (1.34 in.), with watercress being the dominant vegetation and pebble being the dominant substrate, though silt was present to moderate levels (30 percent). In relation to water quality, the average temperature is 14.9 °C (58.82 °F), specific conductivity averages 142.53 µS/cm, and pH averages 8.43. Over the last five surveyed years there has been an average count of 507 springsnails, placing BYB7 in high condition for abundance. The CPUE trendline is positive, does not influence the abundance condition, and indicates that natural recruitment is likely exceeding adult mortality. Because of the natural recruitment, augmentation is in high condition, as population augmentation via released captive springsnails or wild-to-wild translocations is not needed to maintain the population. Over the last five surveyed years, silt has comprised 18 percent of substrates, and crayfish have been detected in four of five surveyed years resulting in a binomial average of 0.8. Thus, BYB7 is in moderate condition for silt and very low condition for crayfish. We therefore consider BYB7 to be in an overall moderate condition.

Current Redundancy

There are 26 springheads across three complexes that currently support or have the potential to support Three Forks springsnail. Of these 26 springheads, three are not known to have historical occurrences, 11 are considered extirpated, and 12 have extant populations. Of the 12 extant populations, eight are in very low condition, two are in low condition, and two are in moderate condition. None of the populations were in a high condition (Figure 12). In the Three Forks Complex, all five populations are extirpated. The Boneyard Creek Complex has three springs with no known historical occurrences, six extant populations in very low condition, and three extirpated populations. The Boneyard Bog Complex is at the top of the watershed (Figure 12). Of the six extant populations in this complex, two each are in moderate, low, and very low condition; and the three other populations are extirpated (Table 8).

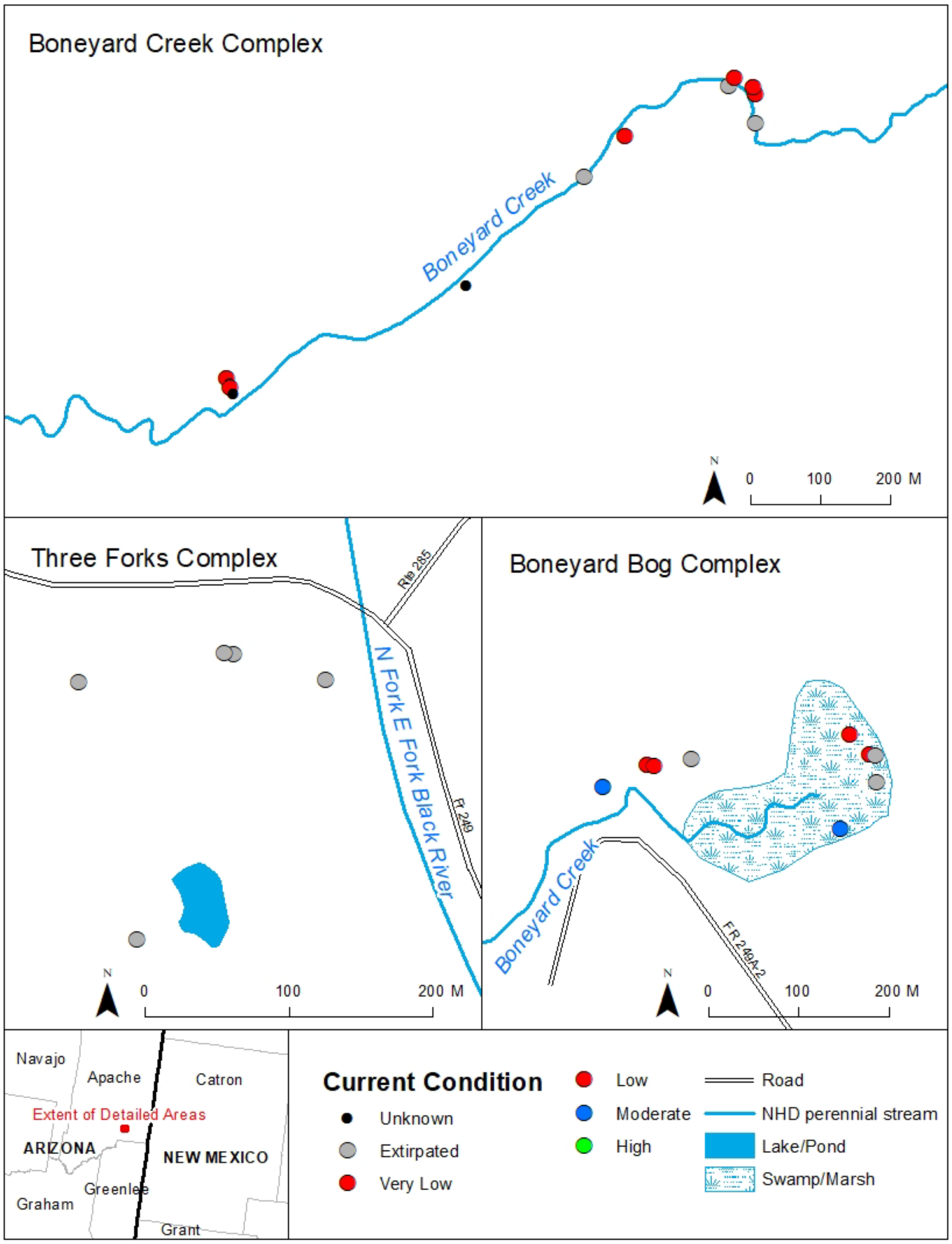

Figure 12. Current occupancy and condition of the three different complexes. Given that populations in low and very low condition require augmentation for population viability, to simplify the figure they are both depicted in red.

In summary, there is no current redundancy of extant populations in the Three Forks Complex, and all six extant populations in the Boneyard Creek Complex have a high risk of extirpation in the near future. The only complex with populations with moderate condition resiliency is the Boneyard Bog Complex, but few (n=2) populations meet that condition; all other extant populations have a moderate (n=2) or high (n=2) risk of becoming extirpated in the near future.

CURRENT REPRESENTATION

Genetic and ecological representation can be influenced by the distribution of and distance between populations across the species' range. The Three Forks springnail's entire range is distributed within three complexes found within 5.95 km (3.7 mi.), predominantly along a single drainage. Historically, only three complexes held all known genetic diversity. Any genetic diversity historically present at the Three Forks Complex was lost approximately 20 years ago during the KP-Three Forks Fire, and there is a high risk of losing remaining genetic diversity in the Boneyard Creek Complex as resiliency for all extant populations is in very low condition. The Boneyard Bog Complex has the only populations (n=2) with resiliency in moderate condition. This is concerning because it is within the highest elevations of the watershed, at 2,575 m (8,450 ft), and therefore most likely to be impacted by climate change and drought. Conversely, the lowest elevation complex in the watershed is the Three Forks Complex. Given its elevation, at 2,507 m (8,228 ft), and location near the confluence of Boneyard Creek and the East Fork of the Black River, it is less likely to be as affected by climate change, but all populations are extirpated, and augmentation is necessary to reestablish populations. However, our understanding of the hydrology of the complexes is still developing. This geographical spread of springs also results in a little genetic representation, and due to the life history of the species, little genetic exchange between populations. Further, each spring can have varying habitat characteristics, and the springsnail requires specific habitat requirements and parameters.

SUMMARY TABLE

Table 8. Current resiliency conditions of Three Forks springsnail populations summarized for Three Forks, Boneyard Creek, and Boneyard Bog complexes.

Complex: Site ID	Abundance	Is Augmentation Needed?	Crayfish	Percent Silt	Overall Condition
Three Forks: NSH	Extirpated	Extirpated	Very Low	Low	Extirpated
Three Forks: SB1A	Extirpated	Extirpated	Moderate	High	Extirpated
Three Forks: SB1B	Extirpated	Extirpated	Moderate	High	Extirpated
Three Forks: SB2	Extirpated	Extirpated	Moderate	High	Extirpated
Three Forks: SB3	Extirpated	Extirpated	Very Low	High	Extirpated
Boneyard Creek: PT1	Extirpated	Extirpated	Moderate	High	Extirpated
Boneyard Creek: PT2	Very Low	Very Low	Moderate	Moderate	Very Low
Boneyard Creek: PT3	Very Low	Very Low	High	High	Very Low
Boneyard Creek: PT4	Extirpated	Extirpated	Low	Moderate	Extirpated
Boneyard Creek: PT5	Very Low	Very Low	Low	High	Very Low
Boneyard Creek: PT6	Extirpated	Extirpated	High	High	Extirpated
Boneyard Creek: PT7	Very Low	Very Low	Low	High	Very Low
Boneyard Creek: PT8	N/A	N/A	High	High	Unknown
Boneyard Creek: Lopez Spring 1	Very Low	Very Low	Very Low	High	Very Low
Boneyard Creek: Lopez Spring 2	N/A	N/A	Very Low	Moderate	Unknown
Boneyard Creek: Lopez Spring 3	Very Low	Very Low	Very Low	Low	Very Low
Boneyard Creek: Lopez Spring 4	N/A	N/A	High	Very Low	Unknown
Boneyard Bog: BYB1	Moderate	High	High	Moderate	Moderate
Boneyard Bog: BYB2A	Very Low	Very Low	Very Low	Low	Very Low
Boneyard Bog: BYB2B	Very Low	Very Low	Very Low	Low	Very Low
Boneyard Bog: BYB3	Extirpated	Extirpated	Low	High	Extirpated
Boneyard Bog: BYB4	Low	Low	Moderate	High	Low-Moderate
Boneyard Bog: BYB5A	Very Low	Very Low	Low	High	Very Low
Boneyard Bog: BYB5B	Extirpated	Extirpated	Low	Low	Extirpated
Boneyard Bog: BYB6	Extirpated	Extirpated	Moderate	Very Low	Extirpated
Boneyard Bog: BYB7	High	High	Very Low	Moderate	Moderate

Chapter 7. Future Condition

Previous chapters include information on Three Forks springsnail ecology, past and current distribution, stressors on viability, and current conditions. Here, the viability of Three Forks springsnail is assessed by applying future forecasts to the species' resiliency, redundancy, and representation through 2050.

DESCRIPTIONS OF FUTURE SCENARIOS

Assumptions

Stressor Assumptions

Based on the best available information, we have made assumptions, summarized below, regarding the likelihood of occurrence and degree of threat for stressors that apply to all four potential future scenarios.

First, crayfish have a high likelihood of occurring throughout the range of the species and will continue to have a high degree of threat. Conversely, for the invasive New Zealand mudsnail, we assume that it will have a low likelihood of occurring in the springsnail's range because the spring water's low range of specific conductivity would inhibit that species' establishment. However, should New Zealand mudsnail become established, it would have a high degree of threat.

Livestock and elk can adversely affect habitat through trampling or wallowing. We assume this has a low likelihood of happening because of the conservation measures already taken by installing fenced enclosures around springs along Boneyard Creek. Boneyard Bog, with the exception of Boneyard Bog 1, is already fenced and excludes livestock but not elk. Should trampling or wallowing occur, it would have a low degree of threat for the springsnail because there is no livestock grazing allotment for the Three Forks area, and conditions of existing elk wallows have not changed over the past 20 years.

Contaminants may enter springsnail habitat through researchers working in the area or through fire-response activities. Both sources are a significant threat because of the sensitivity of the species to water quality. However, the likelihood of contaminants entering a spring from a researcher is assumed to be low because of AZGFD's use of HACCP plans for gear cleaning and disinfection, which are followed during and after field work. The likelihood of contaminants entering a spring from fire suppression actions is assumed to be moderate because, while there is a predicted increase in high-intensity fires in the species' range, it is balanced with the USFS' ongoing consultation which provides guidelines limiting the use of retardant drops.

Climate change is a current stressor and has a high likelihood of impacting the species in the future. The IPCC has provided a variety of Shared Socio-economic Pathway (SSP) greenhouse gas emission scenarios through the year 2100 (SSP1-2.6 or SSP3-8.5; Pörtner et al. 2022 p. 16). Emission levels in the short term will determine which climate change model is most likely to occur. In the interim, we have provided an array of scenarios to encompass a range of IPCC models. For this SSA we consider climate change impacts from SSP1-2.6 in Scenario 1 and Scenario 2 because of currently occurring, and hopefully increasing, climate change adaptation to meet the 2015 Paris Agreement's 2030 and 2050 goals. Scenarios 3 and 4 include SSP3-8.5 should climate change adaptation measures cease and not meet the 2015 Paris Agreement's 2030 and 2050 goals. Projecting out to the 2050 goal also aligns with our estimates for a successful captive population and augmentation of needed populations as described below under Conservation Measure Assumptions.

Based on data from the Environmental Protection Agency (EPA), eastern Arizona has been abnormally dry and continues to have moderate to severe drought conditions (EPA 2021 entire). We assume there will continue to be a high degree of threat from drought to the springsnails because of their dependence on water and because of current drought trends which are due in part to continuing climate change.

Temperature influences dissolved oxygen concentrations in water. Because the rate of springflow can influence water temperature, this stressor is linked to the stressor of drought. Therefore, we assume temperature change to be a moderate degree of threat because as temperatures rise, dissolved oxygen will decrease (Starrett 2004 p. 2). While the springsnail's short generation time likely allows for more rapid adaptability, the species will not remain extant if it is unable to adapt to temperature changes. However, we are not certain if the current rate of temperature change is too rapid to allow for adaptation.

Finally, drying and flooding will have different degrees of erosion potential based on site characteristics. For instance, the Three Forks Complex has a low degree of erosion threat because the springs are both removed from the nearby creek and reinforced by the CCC springboxes. Meanwhile, the Boneyard Creek springs (excluding Lopez Springs populations and population sites and PT 8 because they are set back on hillsides) all have a high degree of erosion threat because they are adjacent to Boneyard Creek and have experienced effects from previous flooding. The Boneyard Bog populations have a low degree of erosion threat based on their elevations and historical impacts of flooding, except BYB2A and BYB2B which are moderate in terms of this threat. Boneyard Bog 2a and BYB2b were flood impacted following the 2011 Wallow Fire.

Conservation Measure Assumptions

For the below scenarios, conservation measures are assumed to fall into one of two categories. The first is that current conservation measures, including population surveys and opportunistic removal of crayfish, will continue. Under this category it is assumed that additional habitat modifications will not occur and that establishment of refugia population(s) will not occur. The second category is an increase of conservation measures. These measures could include additional modifications to springs, such as installation of flashing around enclosure fencing, installation of other enclosure fences, and establishment of one or more refugia populations with subsequent releases into the wild. These additional conservation measures will be based on adaptive management.

For the scenarios we present, we assume that the additional conservation measures taken will be a success because of the Phoenix Zoo's success establishing and maintaining a Huachuca springsnail population and supporting translocations, and because of the ongoing conservation efforts by partners. Our projections are for the next 25 years to allow for a captive population to be established and to be used for successful augmentation of wild populations. This timeframe is based on records for the Huachuca springsnail population, which took two years to reach a population of over 1,000 individuals, and three years to reach their current estimates of over 8,000 individuals. Using these data, and with each augmentation needing a minimum of 200 snails, we anticipate at minimum two wild populations could be augmented each year following the establishment of the minimum captive population of 1,000 snails. If the captive population is more robust, more augmentations could occur. Assuming the minimum number of augmentations is carried out, it would take at least twenty-one years for each population currently considered either extirpated or in low condition (n=21) to be augmented twice, then, allowing for temporary setbacks, we project future scenarios out to 2050. Finally, sites would only be chosen for augmentation if habitat conditions are moderate or high.

The Three Forks springsnail is federally listed as endangered and is a Tier 1, Species of Greatest Conservation Need in Arizona. Given its status, strong partnerships, and the State's Wildlife Action Plan (AZGFD 2022 p. 56, 180, 209, 284, & 338) there is certainty in the continuation of current conservation measures for the springsnail. Therefore, none of the future scenarios assume there will be a discontinuation of the current conservation measures. All Scenarios are summarized in Table 9.

Scenario 1

In Scenario 1 we assume future climatic conditions align with the IPCC's SSP1 – 2.6 model which approximates a 1.8° C increase in global temperature by 2100. Under this scenario, monitoring of currently occupied sites continues, but no additional conservation measures are implemented, and current conservation structures are minimally maintained. Crayfish will continue to invade and further impact populations and population-sites throughout the complexes. Under this scenario, it is expected that the most recent CPUE trendline will continue to be the trend in the future for all populations, possibly resulting in the extirpation of low condition populations if abundance is also currently at a low condition, and that extirpated populations will remain extirpated due to no augmentation occurring. Because of the continuation of the SSP1- 2.6 climate model, it is expected that habitat conditions will remain relatively constant, including silt condition due to fires and floods not changing to a level that could influence springsnail populations.

Scenario 2

In Scenario 2 we assume future climatic conditions align with the IPCC SSP1- 2.6 model, and that crayfish will continue to invade and further impact population and population-sites throughout the complexes. However, under this scenario we assume that additional conservation measures will be taken. These additional conservation measures would include: (1) installation of flashing around fencing perimeter where there are springsnail enclosures; (2) conducting intensive crayfish monitoring and removal after flashing is installed; (3) repatriation of populations and establishment at population-sites; (4) establishing captive populations at the Phoenix Zoo and the AZGFD Pinetop regional office as a refugia populations; and (5) conducting maintenance of enclosure fences; (6) possible installation of additional fences in the Boneyard Bog area; and (7) possible addition of appropriately sized native rock materials around select springs that are more subject to flooding and erosion.

Under this Scenario it is expected that the most recent CPUE trendline will either stay the same or increase due to possible augmentations. A change in condition (increase) will likely apply to those populations that have a moderate augmentation need and would result in increase of CPUE and abundance. CPUE trendlines would be expected to remain the same for populations where there is a low augmentation need category with low presence and abundance. Similarly, extirpated populations could become repatriated due to reintroduction efforts from refugia population establishment and be classified as moderate presence with moderate abundance because of the numbers needed for a population (minimum of 200), with the CPUE trendline becoming positive to indicate an increase in population size. Augmentation category would be low for these previously extirpated populations until natural recruitment is documented and is sufficient to sustain the population. Due to the continuation of the SSP1- 2.6 climate model, it is expected that habitat conditions will remain relatively constant, including silt condition due to wildfires and floods not changing to a level that could influence springsnail populations. Regardless, augmentation would not occur if habitat conditions are low.

Scenario 3

In Scenario 3 we assume future climatic conditions align with the IPCC SSP3-8.5 model, with crayfish abundance becoming high in BYB1, BYB4, and BYB7. Under this model, drought effects are anticipated to be substantial, and wildfires more frequent and at higher intensities. Under this Scenario, additional conservation measures would be taken. These would include: (1) installation of flashing around fencing perimeter where there are springsnail enclosures; (2) conducting intensive crayfish monitoring and removal after flashing is installed; 3) repatriation of populations and establishment at population-sites; (4) establishing captive populations at the Phoenix Zoo and the AZGFD Pinetop regional office as a refugia populations; (5) conducting maintenance of enclosure fences; (6) possible installation of additional fences in the Boneyard Bog area; and (7) the addition of appropriately sized native rock materials around select springs that are more subject to flooding and erosion.

Under this Scenario it is expected that the most recent CPUE trendline will remain the same. Populations are not expected to increase without augmentation because of the likelihood of a decrease in dissolved oxygen due to the higher temperatures and decrease in available water. Augmentation would not occur if habitat conditions are low. The decrease in flowing springheads is most likely to occur in the Boneyard Bog Complex due to its location higher up in the watershed. Extirpated populations could become repatriated through reintroduction efforts from refugia population establishment, but it is likely that these sites would need repeated augmentations. Because of the increase to the SSP3-8.5 climate model, it is expected that habitat conditions will become less suitable, if not uninhabitable. This decrease in suitability could be from changes in water chemistry, like dissolved oxygen, or from an increase in silt due to the likelihood of increased wildfires and flooding under this model.

Scenario 4

In Scenario 4 we assume future climatic conditions align with the IPCC SSP3-8.5 model, with crayfish abundance becoming high in BYB1, BYB4, and BYB7. Under this model, drought effects are anticipated to be substantial, and wildfires more frequent and at higher intensities. Under this Scenario, no additional conservation measures would be taken. There would still be maintenance of the enclosure fences and crayfish monitoring and removal where surveys are done. However, the current trend line of springsnail presence would likely drop at least one condition category due to decreases in abundance. Populations that are already at the low condition category would likely remain low or become extirpated due to lack of augmentation, and extirpated populations would remain extirpated. Because of the increase to the SSP3-8.5 climate model, it is expected that habitat conditions will become less suitable, if not unhabitable. This decrease in suitability could be from changes in water chemistry, like dissolved oxygen, or from an increase in silt due to the likelihood of increased fires and flooding under this model.

Table 9. Future scenarios developed to assess the potential future resiliency of Three Forks springsnail populations and population-sites.

Future Scenario	***Abundance***	***Is augmentation needed?***	***Crayfish***	***Percent Silt***	***Conservation Actions***
1 Continuation of Current Stressor Trends and Conservation Actions	Under this Scenario it is expected that the current presence trendline will continue into the future, possibly resulting in the extirpation of low condition population sites and continued extirpation condition for extirpated sites due to no augmentation occurring.	Yes. However, a refugia population is not established, and augmentation is limited to opportunistic events when host-populations are of sufficient abundance.	Already modified springboxes are free from crayfish, but crayfish impact all unmodified springs.	Habitat conditions will remain relatively constant.	No additional conservation measures and current conservation structures are minimally maintained
2 Continuation of Current Stressor Trends and Increase in Conservation Actions.	Under this Scenario it is expected that population abundance will either remain the same or increase due to possible augmentation. An increase of abundance will likely apply to those that have a moderate augmentation need. Abundance is expected to remain the same if there was a low augmentation need category. Similarly, extirpated sites could become repatriated due to reintroduction efforts from refugia population establishment and be classified as low presence with moderate abundance because of the numbers needed for a population (minimum of 200).	Yes. Increase in conservation measures allows for a refugia population to be established. Augmentation through release of captive snails or wild snails, should host populations be of sufficient abundance, occurs.	Modified springboxes are free of crayfish, but crayfish impact all unmodified springs.	Habitat conditions will remain relatively constant.	Flashing around existing fencing perimeters are installed and both are maintained. Intensive crayfish monitoring and removal conducted after flashing installation and maintenance. One or more captive populations are established. Springboxes and springs are repatriated. Possible installation of additional fences in the Boneyard Bog area as well as the addition of appropriately sized native rock materials around select springs that are more subject to flooding erosion threats.
3 Stressor Increase and Increase in Conservation Actions	No increase in populations is expected without augmentation because of the likelihood of a decrease in dissolved oxygen due to the higher temperatures and decrease in available water. Extirpated sites could become repatriated due to reintroduction efforts from refugia population establishment, but it is likely that these sites will also need repeated augmentations.	Yes. Population augmentation is needed to offset the effects of climate change and stochastic events at most springs regardless of modification status.	Modified springboxes are free of crayfish, but crayfish impact all unmodified springs.	Increase in silt associated with erosion and flooding events. (more associated with springs lower in elevation and close to Boneyard Creek).	Flashing around existing fencing perimeters are installed and both are maintained. Intensive crayfish monitoring and removal conducted after flashing installation and maintenance. Springboxes and springs are repatriated. One or more captive populations are established. Possible installation of additional fences in the Boneyard Bog area as well as the addition of appropriately sized native rock materials around select springs that are more subject to flooding erosion threats.

4 Stressor Increase with no Increase in Conservation Actions	Populations that are already in the low condition category would likely remain low or become extirpated due to lack of augmentation, and extirpated sites would remain extirpated.	Augmentation is needed to offset the effects of climate change and stochastic events, but such augmentation is limited to opportunistic events when host populations are of sufficient abundance.	Already modified springboxes are free from crayfish, but crayfish impact all unmodified springs.	Increase in silt associated with erosion and flooding events. (more associated with springs lower in elevation and close to Boneyard Creek).	No additional conservation measures and current conservation structures are minimally maintained

FUTURE RESILIENCY

Scenario 1

Three Forks Complex

Under Scenario 1, the Three Forks Complex is expected to remain extirpated because no additional conservation actions, such as the establishment of a captive refugia population, are implemented. There are no anticipated changes in the habitat conditions at any of the population sites (NSH, SB1A, SB1B, SB2, or SB3). It is expected that the crayfish presence at the springboxes SB1A, SB1B, and SB2 will remain moderate because of the modifications already done to those sites and continuing opportunistic removal of crayfish. Sites SB3 and NSH are expected to retain a very low condition for crayfish because no additional modifications would be done. Because the Three Forks Complex is the lowest in the watershed, it is expected that these springs are at the lowest risk of decreased flows and dewatering. Therefore, all populations in the Three Forks Complex are expected to retain an overall condition of extirpated under Scenario 1 (Table 10; Figure 13).

Boneyard Creek Complex

Under Scenario 1, the Boneyard Creek Complex is expected to become extirpated because all currently occupied populations are in very low abundance. With fewer than 50 snails observed, it is expected that, without augmentation, these populations are likely to become extirpated in the near future. The two Lopez Springs populations and two population-sites are now within an enclosure that had plastic flashing installed around the perimeter to prevent crayfish. However, with no additional conservation actions implemented under this scenario, these four springheads at Lopez Springs are the only springheads that are likely to exhibit an improved future condition for crayfish. But without augmentation, springsnail abundance is expected to decline, resulting in the extirpation of the two populations at Lopez Springs. Because the Boneyard Creek Complex is in the middle of the watershed, it is expected that these springs are at the moderate risk of decreased flows and dewatering. A summary of conditions under Scenario 1 is available in Table 10, and visually represented in Figure 13.

PT1

Currently, PT1 is considered extirpated. This is not expected to change. Additionally, there are no anticipated changes in the habitat conditions (moderate for crayfish and high for silt) for this population. Overall, PT1 is expected to be in extirpated condition under Scenario 1.

PT2

Currently, PT2 is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Silt and crayfish conditions are both moderate and are not expected to change under this Scenario. Overall PT2 is expected to be in extirpated condition under Scenario 1.

PT3

Currently, PT3 is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated unless augmentation occurs. Silt and crayfish conditions are both high and are not expected to change under this Scenario. Overall PT3 is expected to be in extirpated condition under Scenario 1.

PT4

Currently, PT4 is considered extirpated. This is not expected to change. There are no anticipated changes in the habitat conditions (low for crayfish and moderate for silt) for this population. Overall, PT4 is expected to be in extirpated condition under Scenario 1.

PT5

Currently, PT5 is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Currently, the crayfish condition is low and silt condition is high, and neither are expected to change under this Scenario. Overall PT5 is expected to be in extirpated condition under Scenario 1.

PT6

Currently, PT6 is considered extirpated. This is not expected to change. There are no anticipated changes in the habitat conditions (high for both silt and crayfish) for this population under this Scenario. Overall, PT6 is expected to be in extirpated condition under Scenario 1.

PT7

Currently, PT7 is considered extirpated. This is not expected to change. There are no anticipated changes in the habitat conditions (low for crayfish and high for silt) for this population under this Scenario. Overall, PT7 is expected to be in extirpated condition under Scenario 1.

PT8

Currently, PT8 is in unknown condition meaning that no historical occupancy is known. Silt and crayfish conditions are both high and are not expected to change under this Scenario. Overall, the condition for this population-site is expected to remain unknown under Scenario 1.

Lopez Spring 1 (LS1)

Currently, LS1 is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Currently, the crayfish condition is very low and silt condition is high. However, due to modifications done in 2021, it is expected that the crayfish condition will improve over time, reaching low condition in the near future. The silt condition is not expected to change under this Scenario. Overall LS1 is expected to be in extirpated condition under Scenario 1.

Lopez Spring 2 (LS2)

Currently, LS2 is in unknown condition meaning that no historical occupancy is known. Currently, the crayfish condition is very low and silt condition is moderate. However, due to modifications done in 2021, it is expected that the crayfish condition will improve over time, reaching low condition in the near future. The silt condition is not expected to change under this Scenario. Its overall condition is expected to remain unknown under Scenario 1.

Lopez Spring 3 (LS3)

Currently, LS3 is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Currently, the crayfish condition is very low and silt condition is low. However, due to modifications done in 2021, it is expected that the crayfish condition will improve over time, reaching low condition in the near future. The silt condition is not expected to change under this Scenario. Overall LS3 is expected to be in extirpated condition under Scenario 1.

Lopez Spring 4 (LS4)

Currently, LS4 is in unknown condition meaning that no historical occupancy is known. Currently, the crayfish condition is high despite being in close proximity to sites LS1, LS2, and LS3, but silt condition is very low. The conditions for crayfish and silt are not expected to change under this Scenario. Overall LS4's condition is expected to remain unknown under Scenario 1.

Boneyard Bog Complex

Under Scenario 1, the Boneyard Bog Complex is expected to lose some representation due to some populations currently being in very low abundance and therefore likely to become extirpated. No populations in the Boneyard Bog Complex have enclosure fences or crayfish-prevention. Therefore, with no additional conservation actions to be done through this Scenario, such as population augmentation or installation of fencing and crayfish prevention, conditions within the Boneyard Bog Complex are expected to become worse as crayfish continue to encroach on springs. Silt condition is not expected to change. Because the Boneyard Bog Complex is in the upper part of the watershed, it is expected that these springs are at moderate risk of decreased flows and dewatering because of the relatively small contributing watershed area and changes in precipitation. A summary of conditions under Scenario 1 is available in Table 10, and visually represented in Figure 13.

BYB1

Currently, BYB1 is at moderate abundance and is expected to maintain current levels of recruitment and, therefore, moderate abundance. The condition of crayfish is high and silt condition is moderate. These habitat conditions are not expected to change, and overall BYB1 is expected to remain in moderate condition under Scenario 1.

BYB2A

Currently, BYB2A is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. There are no anticipated changes in the habitat conditions, very low for crayfish and low for silt, at this springhead. Overall BYB2A is expected to remain in extirpated condition under Scenario 1.

BYB2B

Currently, BYB2B is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Currently, the crayfish condition is very low and silt condition is low, and neither are expected to change. Overall, BYB2B is expected to be in extirpated condition under Scenario 1.

BYB3

Currently, BYB3 is considered extirpated. This is not expected to change. There are no anticipated changes in the habitat conditions, low for crayfish and high for silt, at this springhead. Overall, BYB3 is expected to remain in extirpated condition under Scenario 1.

BYB4

Currently, BYB4 is in low abundance. Therefore, it is expected that in the near future this population will become very low abundance. Currently, the crayfish condition is moderate and silt condition is high, neither are expected to change at this springhead. Overall, BYB4 is expected to become very low condition under Scenario 1.

BYB5A

Currently, BYB5A is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Currently, while the crayfish condition is moderate according to the binomial average, the proximity to BYB5B, which is considered low for crayfish, results in BYB5A also being considered low for crayfish. Silt condition is high, and neither silt nor crayfish conditions are expected to change at this springhead. Overall, BYB5A is expected to have an extirpated condition under Scenario 1.

BYB5B

Currently, BYB5B is considered extirpated. This is not expected to change. There are no anticipated changes in the low habitat conditions for both crayfish and silt at this springhead. Overall, BYB5B is expected to remain in extirpated condition under Scenario 1.

BYB6

Currently, BYB6 is considered extirpated. This is not expected to change. There are no anticipated changes in the habitat conditions (moderate for crayfish and very low for silt) at this population. Overall, BYB6 is expected to remain in extirpated condition under Scenario 1.

BYB7

Currently, BYB7 is at high abundance and is expected to maintain current levels of recruitment and remain at high abundance. The condition of crayfish is very low, and silt condition is moderate. These habitat conditions are not expected to change, and overall BYB7 is expected to remain in moderate condition under Scenario 1.

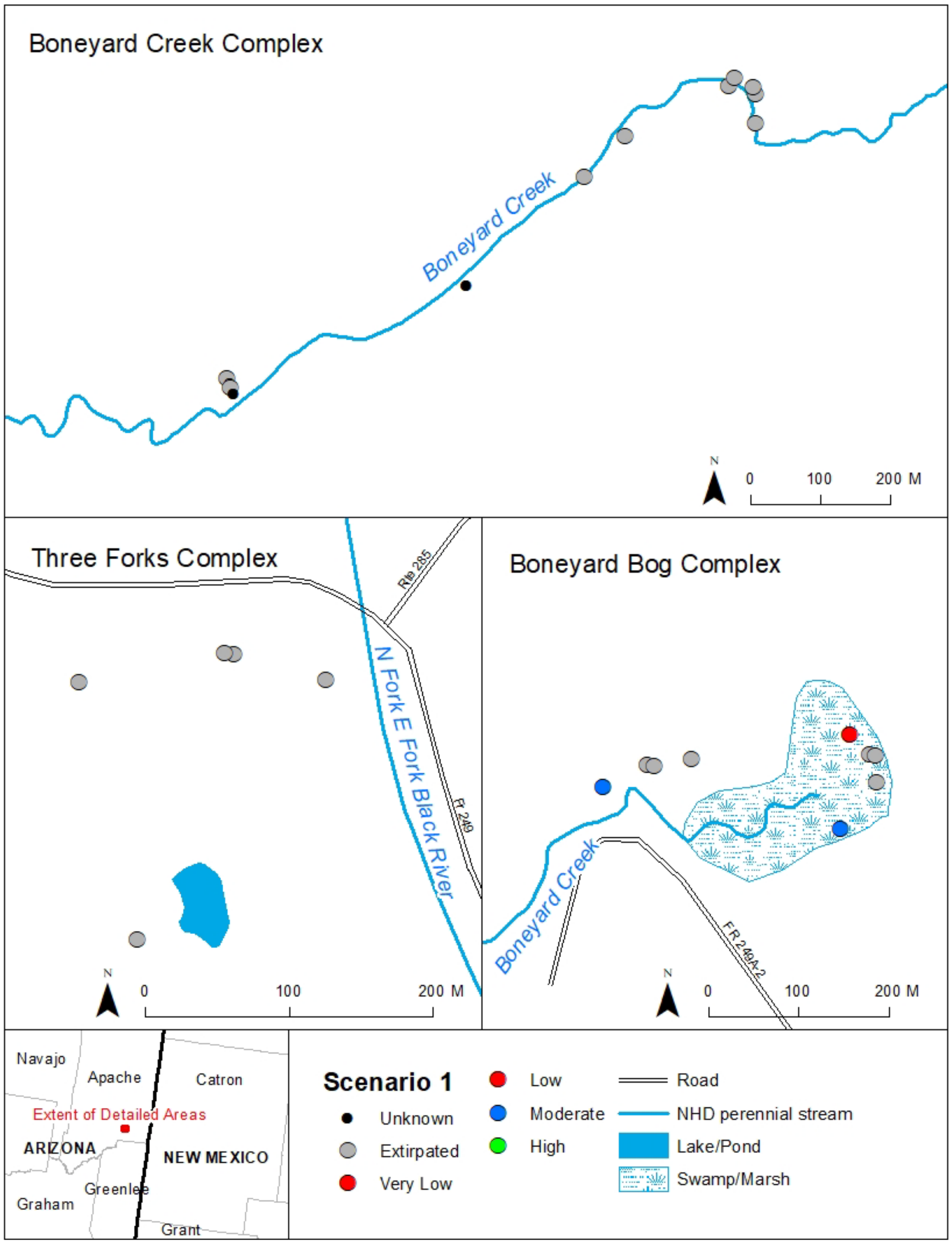

Figure 13. Anticipated future conditions for each site under Scenario 1. Given that populations in low and very low condition require augmentation for population viability, to simplify the figure they are both depicted in red.

Table 10. Potential conditions for each population and population-site under Scenario 1.

Complex: Site ID	Abundance	Is Augmentation Needed?	Crayfish	Percent Silt	Overall Condition
Three Forks: NSH	Extirpated	Extirpated	Very Low	Low	Extirpated
Three Forks: SB1A	Extirpated	Extirpated	Moderate	High	Extirpated
Three Forks: SB1B	Extirpated	Extirpated	Moderate	High	Extirpated
Three Forks: SB2	Extirpated	Extirpated	Moderate	High	Extirpated
Three Forks: SB3	Extirpated	Extirpated	Very Low	High	Extirpated
Boneyard Creek: PT1	Extirpated	Extirpated	Moderate	High	Extirpated
Boneyard Creek: PT2	Extirpated	Extirpated	Moderate	Moderate	Extirpated
Boneyard Creek: PT3	Extirpated	Extirpated	High	High	Extirpated
Boneyard Creek: PT4	Extirpated	Extirpated	Low	Moderate	Extirpated
Boneyard Creek: PT5	Extirpated	Extirpated	Low	High	Extirpated
Boneyard Creek: PT6	Extirpated	Extirpated	High	High	Extirpated
Boneyard Creek: PT7	Extirpated	Extirpated	Low	High	Extirpated
Boneyard Creek: PT8	N/A	N/A	High	High	Unknown
Boneyard Creek: Lopez Spring 1	Extirpated	Extirpated	Low	High	Extirpated
Boneyard Creek: Lopez Spring 2	N/A	N/A	Low	Moderate	Unknown
Boneyard Creek: Lopez Spring 3	Extirpated	Extirpated	Low	Low	Extirpated
Boneyard Creek: Lopez Spring 4	N/A	N/A	High	Very Low	Unknown
Boneyard Bog: BYB1	Moderate	High	High	Moderate	Moderate
Boneyard Bog: BYB2A	Extirpated	Extirpated	Very Low	Low	Extirpated
Boneyard Bog: BYB2B	Extirpated	Extirpated	Very Low	Low	Extirpated
Boneyard Bog: BYB3	Extirpated	Extirpated	Low	High	Extirpated
Boneyard Bog: BYB4	Very Low	Low	Moderate	High	Very Low
Boneyard Bog: BYB5A	Extirpated	Extirpated	Low	High	Extirpated
Boneyard Bog: BYB5B	Extirpated	Extirpated	Low	Low	Extirpated
Boneyard Bog: BYB6	Extirpated	Extirpated	Moderate	Very Low	Extirpated
Boneyard Bog: BYB7	High	High	Very Low	Moderate	Moderate

Scenario 2

Three Forks Complex

Under Scenario 2, the Three Forks Complex is expected to become reestablished over time because additional conservation actions, such as the establishment of a captive refugia population and releases of springsnails, will be taken. It is expected that the crayfish presence at SB1A, SB1B and SB2 will remain moderate because of the modifications already completed at those sites and continuing opportunistic removal of crayfish. It is expected that an enclosure fence and flashing will be installed around NSH, and SB3 will have additional modifications to help improve the crayfish conditions. We assume that all of these additional conservation measures will be successful. Because the Three Forks Complex is the lowest in the watershed, it is expected that these springs are at the lowest risk of decreased flows and dewatering. A summary of conditions under Scenario 2 is available in Table 11, and visually represented in Figure 14.

Natural Spring Head (NSH)

With the installation of an enclosure fence and flashing around the perimeter to prevent crayfish access, it is expected that the condition of NSH will improve overtime, reaching low condition. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. There is no expected change in the low condition of silt. Overall, the potential future condition for NSH is low under Scenario 2.

Springbox 1 (SB1A and 1B)

Because of existing modifications, there are no anticipated changes in the habitat conditions of these populations. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. Overall, the potential condition for SB1A and SB1B is moderate under Scenario 2.

Springbox 2 (SB2)

Because of existing modifications, there are no anticipated changes in the habitat conditions of this populations. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. Overall, the potential condition for SB2 is moderate under Scenario 2.

Springbox 3 (SB3)

With additional modifications to prevent crayfish access, it is expected that the condition of SB3 will improve overtime, beginning with reaching low condition. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. Overall, the potential condition for SB3 is moderate under Scenario 2.

Boneyard Creek Complex

Under Scenario 2, the Boneyard Creek Complex is expected to have increased redundancy as populations or population-sites, if chosen for augmentation, are reestablished following additional conservation actions, such as the establishment of a captive refugia population. Further, it is expected that flashing will be installed around the existing enclosure fences to help improve the crayfish conditions at springheads. We assume that all of these additional conservation measures will be successful. Because the Boneyard Creek Complex is in the middle of the watershed, it is expected that these springs are at moderate risk of decreased flows and dewatering. A summary of conditions under Scenario 2 is available in Table 11, and visually represented in Figure 14.

PT1

Currently, PT1 is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current moderate condition to possibly high condition. Silt condition is at high and is not expected to change for this population. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

PT2

Currently, PT2 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current moderate condition to possibly high condition. Silt condition is at moderate and is not expected to change for this population. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

PT3

Currently, PT3 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. While crayfish condition is high for PT3, flashing would be installed along the enclosure fence perimeter. Silt condition is at high and is not expected to change for this population. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

PT4

Currently, PT4 is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. There are no anticipated changes to the moderate condition of silt. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

PT5

Currently, PT5 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to the introduction of no fewer than 200 springsnails at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. There are no anticipated changes to the high condition of silt. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

PT6

Currently, PT6 is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to the introduction of no fewer than 200 springsnails at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. While crayfish condition is high for PT6, flashing would be installed along the enclosure fence perimeter. There are no anticipated changes in the high condition of silt for this population. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

PT7

Currently, PT7 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to the introduction of no fewer than 200 springsnails at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. There are no anticipated changes to the high condition of silt. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

PT8

The population site PT8 is of unknown historical occupancy, and currently has no springsnails present. However, if chosen for augmentation, abundance would automatically become moderate due to the introduction of no fewer than 200 springsnails at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. An enclosure fence, and associated flashing around the perimeter, are both recommended for this site as additional conservation measures to maintain the high condition of crayfish. The high condition of silt is not anticipated to change. Overall, this population-site is in unknown condition under Scenario 2 because of its unknown historical occupancy and uncertainty on success of conservation measures.

Lopez Spring 1 (LS1)

Currently, LS1 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current very low condition to low condition. There are no anticipated changes to the high condition of silt. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

Lopez Spring 2 (LS2)

The population site LS2 is of unknown historical occupancy, and currently has no springsnail present. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current very low condition to low condition. There are no anticipated changes to the moderate condition of silt. Overall, this population-site is in unknown condition under Scenario 2 because of its unknown historical occupancy and uncertainty on success of conservation measures.

Lopez Spring 3 (LS3)

Currently, LS3 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current very low condition to low condition. There are no anticipated changes to the low condition of silt. Overall, this population would be in low overall condition under Scenario 2.

Lopez Spring 4 (LS4)

The population site LS4 is of unknown historical occupancy, and currently has no springsnail present. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will remain at high condition. There are no anticipated changes to the low condition of silt. Overall, this population-site is in unknown condition under Scenario 2 because of its unknown historical occupancy and uncertainty on success of conservation measures.

Boneyard Bog Complex

Under Scenario 2, the Boneyard Bog Complex is expected to have increased redundancy as populations are augmented or reestablished because additional conservation actions, such as the establishment of a captive refugia population, will be taken. Further, it is expected that as enclosure fencing, and flashing is installed, there will be improvements to the crayfish conditions at these springheads. We do assume that all of these additional conservation measures will be successful. Because the Boneyard Bog Complex is high in the watershed, it is expected that these springs are at moderate risk of decreased flows and dewatering because of projections of future precipitation and limited tributaries. A summary of conditions under Scenario 2 is available in Table 11, and visually represented in Figure 14.

BYB1

Currently, BYB1 is at moderate abundance and is expected to maintain current levels of recruitment and remain at moderate abundance. An enclosure fence, and associated flashing around the perimeter, are both recommended for this population as additional conservation measures to maintain the high condition of crayfish. The moderate condition of silt is not anticipated to change. Overall, this population is in moderate condition under Scenario 2.

BYB2A

Currently, BYB2A is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of fencing and flashing, we anticipate crayfish condition will improve from the current very low condition to low condition. There are no anticipated changes to the low condition of silt. Overall, this population would be in low condition under Scenario 2.

BYB2B

Currently, BYB2B is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current very low condition to low condition. There are no anticipated changes to the low condition of silt. Overall, this population would be in low condition under Scenario 2.

BYB3

Currently, BYB3 is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of fencing and flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. There are no anticipated changes to the high condition of silt. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

BYB4

Currently, BYB4 is in low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current moderate condition to high condition. There are no anticipated changes to the high condition of silt. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

BYB5A

Currently, BYB5A is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. There are no anticipated changes to the high condition of silt. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

BYB5B

Currently, BYB5B is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of fencing and flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. There are no anticipated changes to the low condition of silt. Overall, this population would be in low overall condition under Scenario 2.

BYB6

Currently, BYB6 is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of fencing and flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. There are no anticipated changes to the very low condition of silt. Overall, this population would be in low overall condition under Scenario 2.

BYB7

Currently, BYB7 is at high abundance and is expected to maintain current levels of recruitment and remain at high abundance. With the installation of fencing and flashing, we anticipate crayfish condition will improve from the current very low condition to low condition. There are no anticipated changes to the moderate condition of silt. Assuming augmentation occurs, this population would be in moderate overall condition under Scenario 2.

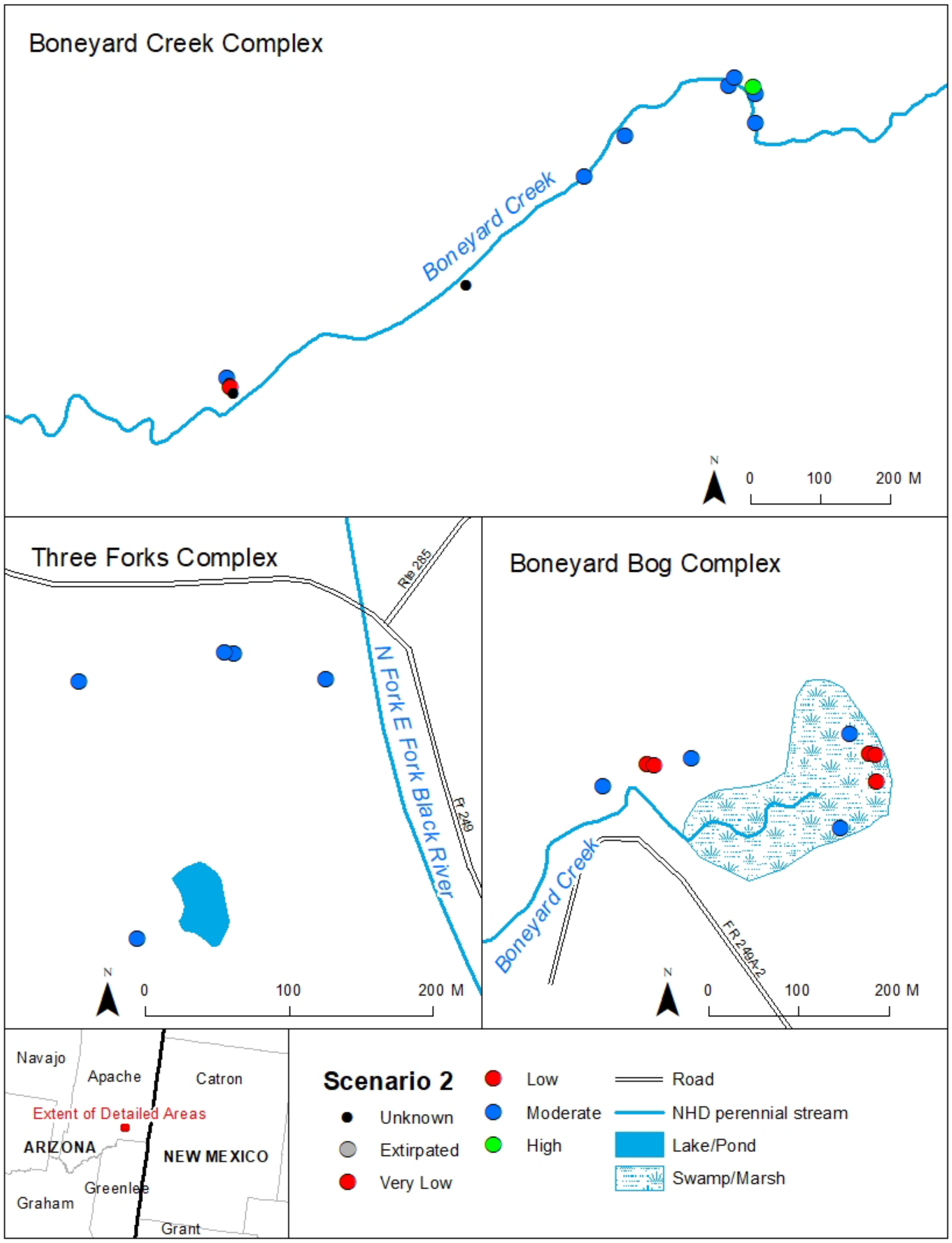

Figure 14. Anticipated future conditions for each site under Scenario 2. *Given that populations in low and very low condition require augmentation for population viability, to simplify the figure they are both depicted in red.*

Table 11. Potential conditions for each population and population-site under Scenario 2.

Complex: Site ID	***Abundance***	***Is Augmentation Needed?***	***Crayfish***	***Percent Silt***	***Overall Condition***
Three Forks: NSH	Moderate	Low	Low	Low	Low
Three Forks: SB1A	Moderate	Low	Moderate	High	Moderate
Three Forks: SB1B	Moderate	Low	Moderate	High	Moderate
Three Forks: SB2	Moderate	Low	Moderate	High	Moderate
Three Forks: SB3	Moderate	Low	Low	High	Moderate
Boneyard Creek: PT1	Moderate	Low	High	High	Moderate
Boneyard Creek: PT2	Moderate	Moderate	High	Moderate	Moderate
Boneyard Creek: PT3	Moderate	Moderate	High	High	Moderate
Boneyard Creek: PT4	Moderate	Low	Moderate	Moderate	Moderate
Boneyard Creek: PT5	Moderate	Low	Moderate	High	Moderate
Boneyard Creek: PT6	Moderate	Low	High	High	Moderate
Boneyard Creek: PT7	Moderate	Low	Moderate	High	Moderate
Boneyard Creek: PT8	N/A	N/A	High	High	Unknown
Boneyard Creek: Lopez Spring 1	Moderate	Low	Low	High	Moderate
Boneyard Creek: Lopez Spring 2	N/A	N/A	Low	Moderate	Unknown
Boneyard Creek: Lopez Spring 3	Moderate	Low	Low	Low	Low
Boneyard Creek: Lopez Spring 4	N/A	N/A	High	Very Low	Unknown
Boneyard Bog: BYB1	Moderate	High	High	Moderate	Moderate
Boneyard Bog: BYB2A	Moderate	Low	Low	Low	Low
Boneyard Bog: BYB2B	Moderate	Low	Low	Low	Low
Boneyard Bog: BYB3	Moderate	Low	Moderate	High	Moderate
Boneyard Bog: BYB4	Moderate	Low	High	High	Moderate
Boneyard Bog: BYB5A	Moderate	Low	Moderate	High	Moderate
Boneyard Bog: BYB5B	Moderate	Low	Moderate	Low	Low
Boneyard Bog: BYB6	Moderate	Low	Moderate	Very Low	Low
Boneyard Bog: BYB7	High	High	Low	Moderate	Moderate

Scenario 3

Three Forks Complex

Under Scenario 3, the Three Forks Complex is expected to become reestablished over time because additional conservation actions, such as the establishment of a captive refugia population, will be taken. It is expected that the crayfish presence at the SB1A, SB1B, and SB2 will remain moderate because of the modifications already implemented and continuing opportunistic removals of crayfish. It is expected that an enclosure fence and flashing will be installed around NSH, and SB3 will have additional modifications to help improve the crayfish conditions for those populations. We do assume that all of these additional conservation measures will be successful. Because the Three Forks Complex is the lowest in the watershed, it is expected that these springs are at the lowest risk of decreased flows and dewatering. A summary of conditions under Scenario 3 is available in Table 12, and visually represented in Figure 15.

Natural Spring Head (NSH)

With the installation of an enclosure fence and flashing around the perimeter to prevent crayfish access, it is expected that the condition of NSH will improve overtime, beginning with becoming low condition. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. There is no expected change in the low condition of silt. Overall, the potential condition for NSH is low under Scenario 3.

Springbox 1 (SB1A and 1B)

With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. Overall, the potential condition for SB1A and SB1B is moderate under Scenario 3.

Springbox 2 (SB2)

With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. Overall, the potential condition for SB2 is moderate for Scenario 3.

Springbox 3 (SB3)

With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. With additional modifications to prevent crayfish access, it is expected that the condition of SB3 will improve overtime, beginning with becoming low condition. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. Overall, the potential condition for SB3 is moderate under Scenario 3.

Boneyard Creek Complex

Under Scenario 3, the Boneyard Creek Complex is expected to have increased redundancy as populations or population-sites, if chosen for augmentation, are reestablished because additional conservation actions, such as the establishment of a captive refugia population, will be taken. Further, it is expected that flashing will be installed around the existing enclosure fences to help improve the crayfish conditions. We do assume that all of these additional conservation measures will be successful. Because the Boneyard Creek Complex is in the middle of the watershed, it is expected that these springs are at moderate risk of decreased flows and dewatering which we anticipate being more prevalent under this Scenario. A summary of conditions under Scenario 3 is available in Table 12, and visually represented in Figure 15.

PT1

Currently, PT1 is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current moderate condition to possibly high condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, the placement of appropriately sized native rock materials to shield the spring from flood effects in the future could be a potential conservation action. Overall, the potential condition for PT1 is moderate under Scenario 3.

PT2

Currently, PT2 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current moderate condition to possibly high condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from moderate condition to low condition because of decreased water flows. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, a potential conservation action would be to place appropriately sized native rock materials to shield the spring from flood effects in the future. Overall, the potential condition for PT2 is low under Scenario 3.

PT3

Currently, PT3 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. While crayfish condition is high for PT3, flashing would still be installed along the enclosure fence perimeter. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, one potential conservation action would be to place appropriately sized native rock materials to shield the spring from flood effects in the future. Overall, the potential condition for PT3 is moderate under Scenario 3.

PT4

Currently, PT4 is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from moderate condition to low condition because of decreased water flows. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, one potential conservation action would be to place appropriately sized native rock materials to shield the spring from flood effects in the future. Overall, the potential condition for PT4 is low under Scenario 3.

PT5

Currently, PT5 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Overall, the potential condition for PT5 is moderate under Scenario 3.

PT6

Currently, PT6 is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time.

Augmentation condition would be considered low until recruitment is sufficient to maintain the population. While crayfish condition is high for PT6, flashing would still be installed along the enclosure fence perimeter. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Overall, the potential condition for PT6 is moderate under Scenario 3.

PT7

Currently, PT7 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, one potential conservation action would be to place appropriately sized native rock materials to shield the spring from flood effects in the future. Overall, the potential condition for PT7 is moderate under Scenario 3.

PT8

The population-site PT8 is an unknown historical occupancy, and currently has no springsnails present. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. An enclosure fence, and associated flashing around the perimeter, are both recommended for this population-site as additional conservation measures to maintain the high condition of crayfish. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Overall, this population-site is in unknown condition under Scenario 3 because of its unknown historical occupancy and uncertainty on success of conservation measures.

Lopez Spring 1(LS1)

Currently, LS1 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current very low condition to moderate condition. There are no anticipated changes to the high condition of silt. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Overall, the potential condition for LS1 is moderate under Scenario 3.

Lopez Spring 2 (LS2)

The population-site LS2 is of unknown historical occupancy, and currently has no springsnails. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current very low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from moderate condition to low condition. Overall, this population-site is in unknown condition under Scenario 3 because of its unknown historical occupancy and uncertainty on success of conservation measures.

Lopez Spring 3 (LS3)

Currently, LS3 is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current very low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from low condition to very low condition. Overall, this population would be in low condition under Scenario 3.

Lopez Spring 4 (LS4)

The population-site LS4 is of unknown historical occupancy, and currently has no springsnails. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will remain at high condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from low condition to very low condition. Overall, this population-site is in unknown condition under Scenario 3 because of its unknown historical occupancy and uncertainty on success of conservation measures.

Boneyard Bog Complex

Under Scenario 3, the Boneyard Bog Complex is expected to have increased redundancy as populations are augmented or reestablished because additional conservation actions, such as the establishment of a captive refugia population, will be taken. Further, it is expected that as enclosure fencing and flashing are installed, there will be improvements to the crayfish conditions. We do assume that all additional conservation measures will be successful. However, because the Boneyard Bog Complex is the highest in the watershed, it is expected that these springs are at highest risk of decreased flows and dewatering. A summary of conditions under Scenario 3 is available in Table 12, and visually represented in Figure 15.

BYB1

Currently, BYB1 is at moderate abundance and is expected to maintain current levels of recruitment and remain at moderate abundance. An enclosure fence and associated flashing around the perimeter, are both recommended for this site as additional conservation measures to maintain the high condition of crayfish. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from moderate condition to low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, the placement of appropriately sized native rock materials to shield the spring from flood effects in the future could be a potential conservation action. Overall, this population is in low condition under Scenario 3.

BYB2A

Currently, BYB2A is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of fencing and flashing, we anticipate crayfish condition will improve from the current very low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from low condition to very low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, one potential conservation action would be to place appropriately sized native rock materials to shield the spring from flood effects in the future. Overall, this population would be in low condition under Scenario 3.

BYB2B

Currently, BYB2B is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current very low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from low condition to very low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, one potential conservation action would be to place appropriately sized native rock materials to shield the spring from flood effects in the future. Overall, this population would be in low condition under Scenario 3.

BYB3

Currently, BYB3 is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of fencing and flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, one potential conservation action would be to place appropriately sized native rock materials to shield the spring from flood effects in the future. Overall, this population would be in moderate overall condition under Scenario 3.

BYB4

Currently, BYB4 is in low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from current moderate condition to high condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Overall, this population would be in moderate overall condition under Scenario 3.

BYB5A

Currently, BYB5A is in very low abundance. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, one potential conservation action would be the placement of appropriately sized native rock materials to shield the spring from flood effects in the future. Overall, this population would be in low condition under Scenario 3.

BYB5B

Currently, BYB5B is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of fencing and flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from low condition to very low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, one potential conservation action is the placement of appropriately sized native rock materials to shield the spring from flood effects in the future. Overall, this population would be in low condition under Scenario 3.

BYB6

Currently, BYB6 is considered extirpated. However, if chosen for augmentation, abundance would automatically become moderate due to no fewer than 200 springsnails being introduced at a time. Augmentation condition would be considered low until recruitment is sufficient to maintain the population. With the installation of fencing and flashing, we anticipate crayfish condition will improve from the current low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from low condition to very low condition. Overall, this population would be in low condition under Scenario 3.

BYB7

Currently, BYB7 is at high abundance. However, with the anticipated changes in climate, and possibly water availability, abundance and recruitment are expected to decrease to moderate. With the installation of fencing and flashing, we anticipate crayfish condition will improve from the current very low condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from moderate condition to low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. Because of this, one potential conservation action is the placement of appropriately sized native rock materials to shield the spring from flood effects in the future. Overall, this population would be in moderate condition under Scenario 3.

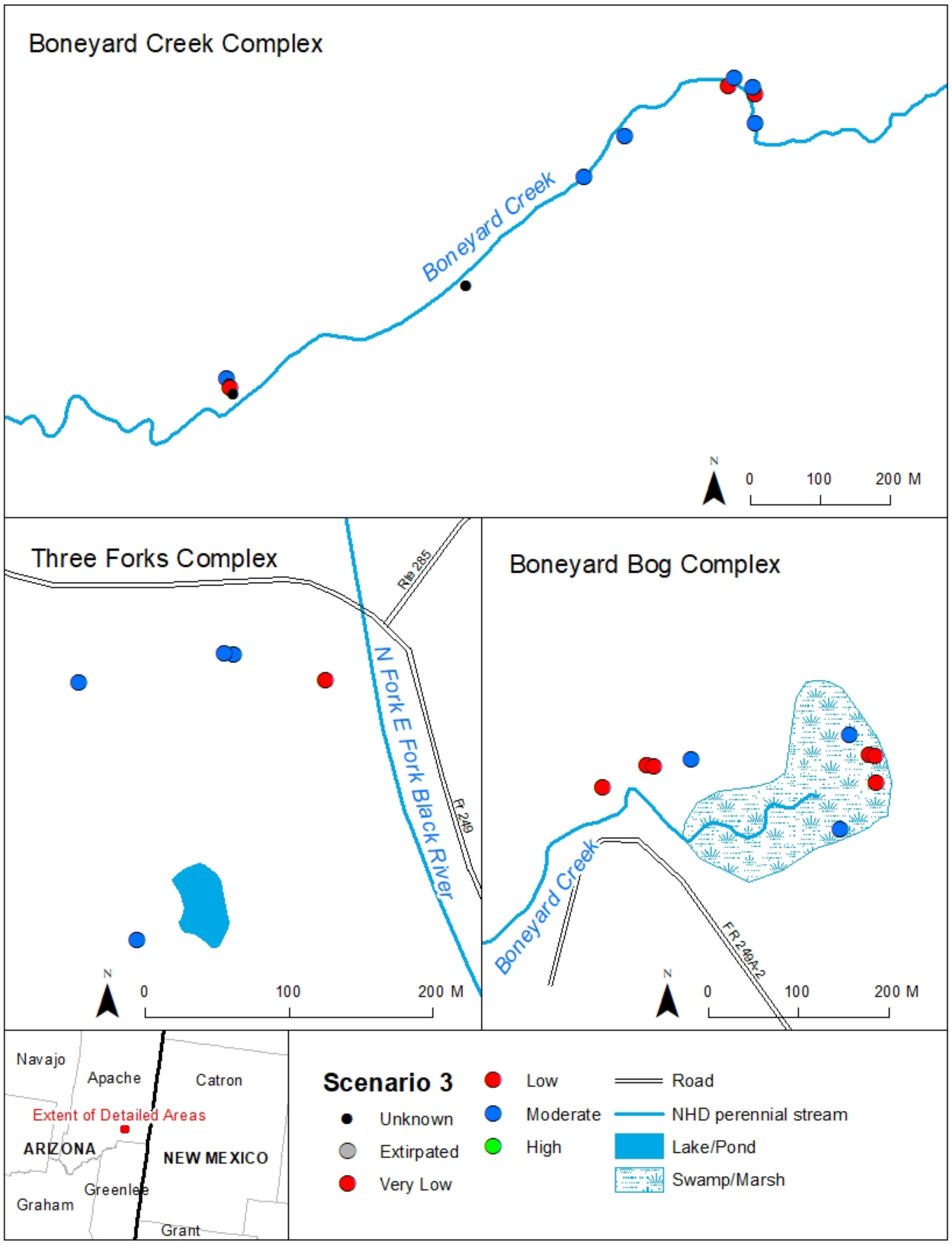

Figure 15. Anticipated future conditions for each site under Scenario 3. Given that populations in low and very low condition require augmentation for population viability, to simplify the figure they are both depicted in red.

Table 12. Potential conditions for each population and population-site under Scenario 3.

Complex: Site ID	*Abundance*	*Is Augmentation Needed?*	*Crayfish*	*Percent Silt*	*Overall Condition*
Three Forks: NSH	Moderate	Low	Moderate	Low	Low
Three Forks: SB1A	Moderate	Low	Moderate	Moderate	Moderate
Three Forks: SB1B	Moderate	Low	Moderate	Moderate	Moderate
Three Forks: SB2	Moderate	Low	Moderate	Moderate	Moderate
Three Forks: SB3	Moderate	Low	Moderate	Moderate	Moderate
Boneyard Creek: PT1	Moderate	Low	High	Moderate	Moderate
Boneyard Creek: PT2	Moderate	Low	Moderate	Low	Low
Boneyard Creek: PT3	Moderate	Low	High	Moderate	Moderate
Boneyard Creek: PT4	Moderate	Low	Moderate	Low	Low
Boneyard Creek: PT5	Moderate	Low	Moderate	Moderate	Moderate
Boneyard Creek: PT6	Moderate	Low	High	Moderate	Moderate
Boneyard Creek: PT7	Moderate	Low	Moderate	Moderate	Moderate
Boneyard Creek: PT8	N/A	N/A	High	Moderate	Unknown
Boneyard Creek: Lopez Spring 1	Moderate	Low	Moderate	Moderate	Moderate
Boneyard Creek: Lopez Spring 2	N/A	N/A	Moderate	Low	Unknown
Boneyard Creek: Lopez Spring 3	Moderate	Low	Moderate	Very Low	Low
Boneyard Creek: Lopez Spring 4	N/A	N/A	High	Very Low	Unknown
Boneyard Bog: BYB1	Moderate	Moderate	High	Low	Low
Boneyard Bog: BYB2A	Moderate	Low	Moderate	Very Low	Low
Boneyard Bog: BYB2B	Moderate	Moderate	Moderate	Very Low	Low
Boneyard Bog: BYB3	Moderate	Low	Moderate	Moderate	Moderate
Boneyard Bog: BYB4	Moderate	Moderate	High	Moderate	Moderate
Boneyard Bog: BYB5A	Moderate	Low	Moderate	Moderate	Low
Boneyard Bog: BYB5B	Moderate	Low	Moderate	Very Low	Low
Boneyard Bog: BYB6	Moderate	Low	High	Very Low	Low
Boneyard Bog: BYB7	Moderate	Moderate	Moderate	Low	Moderate

Scenario 4

Three Forks Complex

Under Scenario 4, the Three Forks Complex is expected to remain extirpated because of no additional conservation actions, such as the establishment of a captive refugia population, being taken. It is expected that the crayfish presence at the SB1A, SB1B, and SB2 will remain moderate because of the modifications already implemented and continuing opportunistic removal of crayfish. For SPB3, condition is expected to remain at very low condition for crayfish because of no additional modifications are implemented. Because the Three Forks Complex is the lowest in the watershed, it is expected that these springs are at the lowest risk of decreased flows and dewatering. A summary of conditions under Scenario 4 is available in Table 13, and visually represented in Figure 16.

Natural Spring Head (NSH)

There are no anticipated changes in the habitat conditions of this population. This population is expected to remain extirpated under Scenario 4.

Springbox 1 (SB1A and 1B)

With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. These populations are expected to remain extirpated under Scenario 4.

Springbox 2 (SB2)

With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. This population is expected to remain extirpated under Scenario 4.

Springbox 3 (SB3)

With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. However, this population is expected to remain extirpated under Scenario 4.

Boneyard Creek Complex

Under Scenario 4, the Boneyard Creek Complex is expected to become extirpated because all currently occupied populations are in very low abundance. By being in very low abundance, it is expected that without augmentation it is likely that the population will become extirpated in the near future. The Lopez Springs springheads are now within an enclosure that had plastic-flashing installed around the perimeter to prevent crayfish and are expected to be the only springheads likely to have an improved crayfish condition. However, with no additional conservation actions to be taken through this scenario, such as continued installation of crayfish prevention, the Boneyard Creek Complex is expected to have continued low condition for crayfish. Because the Boneyard Creek Complex is in the middle of the watershed, it is expected that these springs are at the moderate risk of decreased flows and dewatering. A summary of conditions under Scenario 4 is available in Table 13, and visually represented in Figure 16.

PT1

Currently, PT1 is considered extirpated. This is not expected to change. Crayfish presence is expected to change from moderate condition to low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high condition to moderate condition because of decreased water flows. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter springhead. Overall, this population is expected to be in extirpated condition under Scenario 4.

PT2

Currently, PT2 is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Crayfish presence is expected to change from moderate condition to low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from moderate to low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, this population is expected to be in extirpated condition under Scenario 4.

PT3

Currently, PT3 is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Crayfish presence is expected to change from high condition to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high to moderate condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, this population is expected to be in extirpated condition under Scenario 4.

PT4

Currently, PT4 is considered extirpated. This is not expected to change. Crayfish presence is expected to change from low to very low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from moderate to low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, this population is expected to be in extirpated condition under Scenario 4.

PT5

Currently, PT5 is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Crayfish presence is expected to change from low to very low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high to moderate condition. Overall, this population is expected to be in extirpated condition under Scenario 4.

PT6

Currently, PT6 is considered extirpated. This is not expected to change. Crayfish presence is expected to change from high to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high to moderate condition. Overall, this population is expected to be in extirpated condition under Scenario 4.

PT7

Currently, PT7 is considered extirpated. This is not expected to change. Crayfish presence is expected to change from low to very low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high to moderate condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, this population is expected to be in extirpated condition under Scenario 4.

PT8

Currently, PT8 is of unknown historical occupancy. Crayfish presence is expected to change from high to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high to moderate condition. Overall, this population-site is expected to remain in unknown condition under Scenario 4.

Lopez Spring 1 (LS1)

Currently, LS1 is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Currently, the crayfish condition is very low and silt condition is high. However, due to modifications done in 2021, it is expected that the crayfish condition will improve over time, beginning with becoming low condition in the near future. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high to moderate condition. Overall, this population is expected to be in extirpated condition under Scenario 4.

Lopez Spring 2 (LS2)

Currently, LS2 is of unknown historical occupancy. Currently, the crayfish condition is very low and silt condition is moderate. However, due to modifications done in 2021, it is expected that the crayfish condition will improve over time, beginning with becoming low condition in the near future. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high to moderate condition. Overall, this population-site is expected to remain unknown under Scenario 4.

Lopez Spring 3 (LS3)

Currently, LS3 is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated. Currently, the crayfish condition is very low and silt condition is low. However, due to modifications done in 2021, it is expected that the crayfish condition will improve over time, reaching low condition in the near future. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from low to very low condition. Overall, this population is expected to be in extirpated condition under Scenario 4.

Lopez Spring 4 (LS4)

Currently, LS4 is of unknown historical occupancy. Currently, the crayfish condition is high despite being in close proximity to LS1, LS2, and LS3. It is expected that the 2021 modifications done to prevent crayfish access will maintain this condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions remaining in very low condition. Overall, this population-site is expected to remain unknown under Scenario 4.

Boneyard Bog Complex

Under Scenario 4, the Boneyard Bog Complex is expected to lose representation due to most populations currently being very low abundance and therefore likely to become extirpated. No populations in the Boneyard Bog Complex have enclosure fences or crayfish-prevention. Therefore, with no additional conservation actions to be done through this Scenario, such as development of a refugia-stock population to augment or installation of fencing and crayfish prevention, populations in Boneyard Bog are expected to have decreased crayfish condition. Boneyard Bog is expected to experience changes in silt condition as well because of this continuing encroachment of crayfish, being at the top of the watershed which puts the springs at the highest risk of decreased flows and dewatering and being in the highest risk of flooding effects. A summary of conditions under Scenario 4 is available in Table 13, and visually represented in Figure 16.

BYB1

Currently, BYB1 has moderate abundance. However, it is expected that in the near future this population will become low abundance and crayfish presence is expected to change from high to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from moderate to low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, this population is expected to be in low condition under Scenario 4.

BYB2A

Currently, BYB2A is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated and crayfish presence is expected to change from low to very low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from low to very low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, this population is expected to be in extirpated condition under Scenario 4.

BYB2B

Currently, BYB2B is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated and crayfish presence is expected to change from low to very low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from low to very low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall BYB2B is expected to be in extirpated condition under Scenario 4.

BYB3

Currently, BYB3 is considered extirpated. This is not expected to change. Crayfish presence is expected to change from high to moderate condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from moderate to low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, this population is expected to be in extirpated condition under Scenario 4.

BYB4

Currently, BYB4 is in low abundance. Therefore, it is expected that in the near future this population will become very low abundance and crayfish presence is expected to change from moderate to low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high to moderate condition. Overall, BYB4 is expected to become very low condition under Scenario 4.

BYB5A

Currently, BYB5A is in very low abundance. Therefore, it is expected that in the near future this population will become extirpated and crayfish presence is expected to remain at low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from high to moderate condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, BYB5A is expected to be in extirpated condition under Scenario 4.

BYB5B

Currently, BYB5B is considered extirpated. This is not expected to change. Crayfish presence is expected to remain at low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from low to very low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, BYB5B is expected to be in extirpated condition under Scenario 4.

BYB6

Currently, BYB6 is considered extirpated. This is not expected to change. Crayfish presence is expected to change from moderate to low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions remaining at very low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, BYB6 is expected to be in extirpated condition under Scenario 4.

BYB7

Currently, BYB7 is at high abundance. However, it is expected that in the near future this population will become moderate abundance. Crayfish presence is expected to remain in very low condition. With changes in climate and water availability under this scenario, flows are anticipated to decrease. This is expected to result in silt conditions changing from moderate to low condition. Further, this population is at higher risk of flooding effects, which were observed following the Wallow Fire. With no additional conservation actions to shield this population, these potential effects could permanently alter the springhead. Overall, this population is expected to be in low condition under Scenario 4.

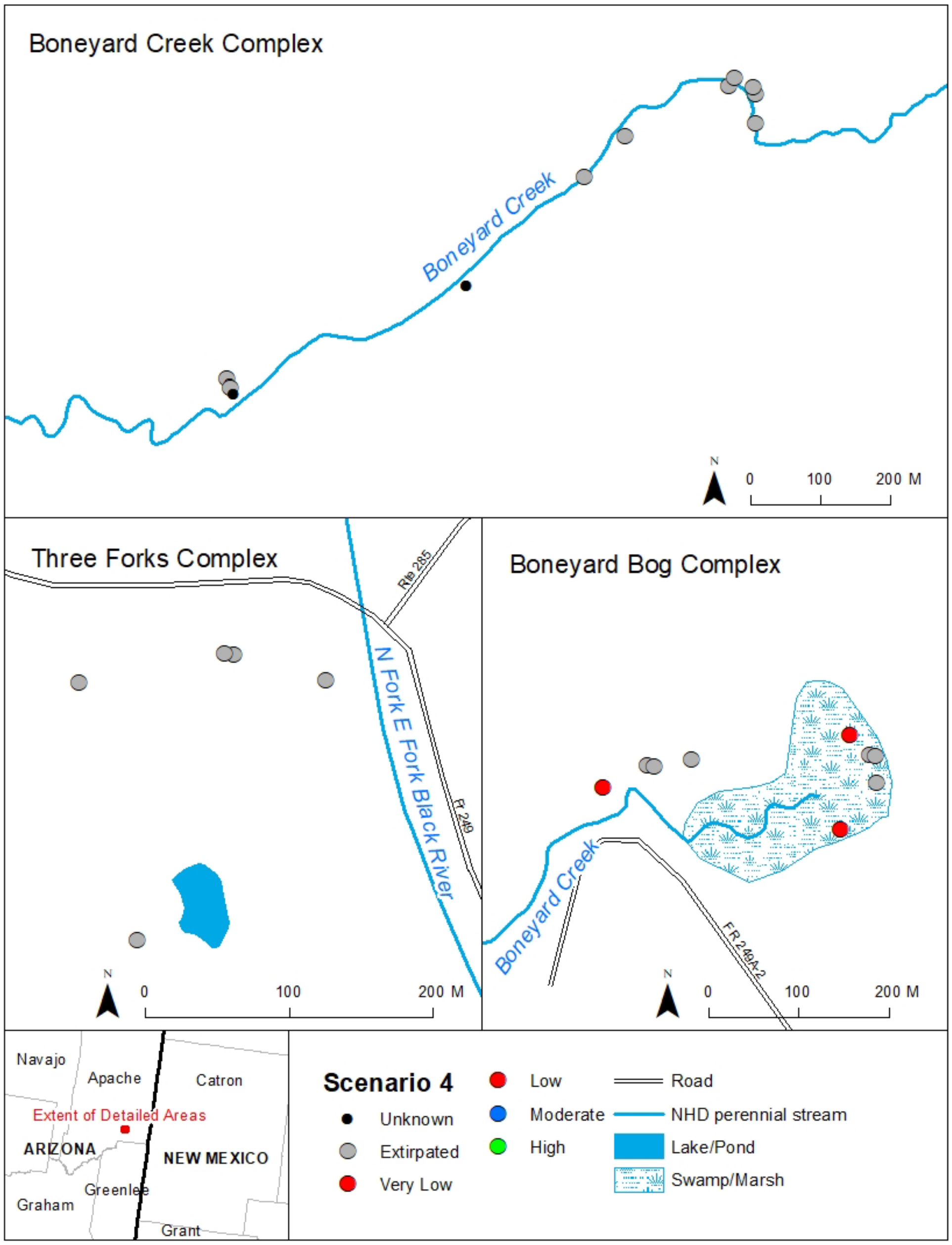

Figure 16. Anticipated future conditions for each site under Scenario 4. Given that populations in low and very low condition require augmentation for population viability, to simplify the figure they are both depicted in red.

Table 13. Potential conditions for each population and population-site under Scenario 4.

Complex: Site ID	*Abundance*	*Is Augmentation Needed?*	*Crayfish*	*Percent Silt*	*Overall Condition*
Three Forks: NSH	**Extirpated**	**Extirpated**	**Very Low**	**Low**	**Extirpated**
Three Forks: SB1A	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Three Forks: SB1B	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Three Forks: SB2	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Three Forks: SB3	**Extirpated**	**Extirpated**	**Very Low**	**Moderate**	**Extirpated**
Boneyard Creek: PT1	**Extirpated**	**Extirpated**	**Low**	**Moderate**	**Extirpated**
Boneyard Creek: PT2	**Extirpated**	**Extirpated**	**Low**	**Low**	**Extirpated**
Boneyard Creek: PT3	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Boneyard Creek: PT4	**Extirpated**	**Extirpated**	**Very Low**	**Low**	**Extirpated**
Boneyard Creek: PT5	**Extirpated**	**Extirpated**	**Very Low**	**Moderate**	**Extirpated**
Boneyard Creek: PT6	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Boneyard Creek: PT7	**Extirpated**	**Extirpated**	**Very Low**	**Moderate**	**Extirpated**
Boneyard Creek: PT8	**N/A**	**N/A**	**Moderate**	**Moderate**	**Unknown**
Boneyard Creek: Lopez Spring 1	**Extirpated**	**Extirpated**	**Low**	**Moderate**	**Extirpated**
Boneyard Creek: Lopez Spring 2	**N/A**	**N/A**	**Low**	**Low**	**Unknown**
Boneyard Creek: Lopez Spring 3	**Extirpated**	**Extirpated**	**Low**	**Very Low**	**Extirpated**
Boneyard Creek: Lopez Spring 4	**N/A**	**N/A**	**High**	**Very Low**	**Unknown**
Boneyard Bog: BYB1	**Low**	**Low**	**Moderate**	**Low**	**Low**
Boneyard Bog: BYB2A	**Extirpated**	**Extirpated**	**Very Low**	**Very Low**	**Extirpated**
Boneyard Bog: BYB2B	**Extirpated**	**Low**	**Very Low**	**Very Low**	**Extirpated**
Boneyard Bog: BYB3	**Extirpated**	**Extirpated**	**Very Low**	**Moderate**	**Extirpated**
Boneyard Bog: BYB4	**Very Low**	**Low**	**Low**	**Moderate**	**Very Low**
Boneyard Bog: BYB5A	**Extirpated**	**Extirpated**	**Low**	**Moderate**	**Extirpated**
Boneyard Bog: BYB5B	**Extirpated**	**Extirpated**	**Low**	**Very Low**	**Extirpated**
Boneyard Bog: BYB6	**Extirpated**	**Extirpated**	**Low**	**Very Low**	**Extirpated**
Boneyard Bog: BYB7	**Moderate**	**Moderate**	**Very Low**	**Low**	**Low**

FUTURE RESILIENCY SUMMARY

We assessed the potential future resiliency of Three Forks springsnail populations through four different but plausible future scenarios. For each scenario, we varied the levels of stressors and conservation efforts going forward based on the current stressors affecting each population, assumptions of future stressors and effects of those stressors, and management efforts going forward. Our assessments of these future scenarios, described in detail above, are summarized and compared to the current condition of each population in Table 14 below.

Table 14. Comparison of current conditions and the potential conditions for each population and population-site under each Scenario.

Complex: Site ID	***Current Condition***	***Scenario 1***	***Scenario 2***	***Scenario 3***	***Scenario 4***
Three Forks: NSH	**Extirpated**	**Extirpated**	**Low**	**Low**	**Extirpated**
Three Forks: SB1A	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Three Forks: SB1B	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Three Forks: SB2	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Three Forks: SB3	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Boneyard Creek: PT1	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Boneyard Creek: PT2	**Very Low**	**Extirpated**	**Moderate**	**Low**	**Extirpated**
Boneyard Creek: PT3	**Very Low**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Boneyard Creek: PT4	**Extirpated**	**Extirpated**	**Moderate**	**Low**	**Extirpated**
Boneyard Creek: PT5	**Very Low**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Boneyard Creek: PT6	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Boneyard Creek: PT7	**Very Low**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Boneyard Creek: PT8	**Unknown**	**Unknown**	**Unknown**	**Unknown**	**Unknown**
Boneyard Creek: Lopez Spring 1	**Very Low**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Boneyard Creek: Lopez Spring 2	**Unknown**	**Unknown**	**Unknown**	**Unknown**	**Unknown**
Boneyard Creek: Lopez Spring 3	**Very Low**	**Extirpated**	**Low**	**Low**	**Extirpated**
Boneyard Creek: Lopez Spring 4	**Unknown**	**Unknown**	**Unknown**	**Unknown**	**Unknown**
Boneyard Bog: BYB1	**Moderate**	**Moderate**	**Moderate**	**Low**	**Low**
Boneyard Bog: BYB2A	**Very Low**	**Extirpated**	**Low**	**Low**	**Extirpated**
Boneyard Bog: BYB2B	**Very Low**	**Extirpated**	**Low**	**Low**	**Extirpated**
Boneyard Bog: BYB3	**Extirpated**	**Extirpated**	**Moderate**	**Moderate**	**Extirpated**
Boneyard Bog: BYB4	**Low**	**Very Low**	**Moderate**	**Moderate**	**Very Low**
Boneyard Bog: BYB5A	**Very Low**	**Extirpated**	**Moderate**	**Low**	**Extirpated**
Boneyard Bog: BYB5B	**Extirpated**	**Extirpated**	**Low**	**Low**	**Extirpated**
Boneyard Bog: BYB6	**Extirpated**	**Extirpated**	**Low**	**Low**	**Extirpated**
Boneyard Bog: BYB7	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Low**

FUTURE REDUNDANCY SUMMARY

Redundancy reduces the risk that a large portion of the species' range will be negatively affected by a catastrophic natural or anthropogenic event. Species that occur as multiple populations distributed across larger ranges are likely less susceptible to extinction than are species that occur as a single population within a smaller range. Because of the endemic nature of the Three Forks springsnail, and current lack of a captive refugia population, the species is inherently susceptible to being affected by natural or anthropogenic events.

Under future Scenario 1, in which current stressor trends continue and there are no additional conservation measures, there is an expected loss of redundancy across the species' range. This loss would be seen by only two populations being moderate condition, with the other populations being either extirpated, or in very low condition (20, and 1 respectively).

Under future Scenario 2, in which current stressor trends continue, but there are additional and assumed successful conservation measures, this redundancy is expected to increase to 17 populations being in moderate condition, and six in low condition. There would also be at least one robust captive refugia population.

Under future Scenario 3, in which current stressors and primarily climate change effects increase, but there are additional and assumed successful conservation measures, redundancy is still expected to increase. However, this increase is shifted slightly, represented by 13 populations in moderate condition, and 10 in low condition. This Scenario would also have at least one robust refugia population.

Under future Scenario 4, in which current stressors and primarily climate change effects increase and where there are no additional conservation measures, there is an expected loss of redundancy across the species' range. This loss would be seen by only three populations remaining extant, of which two would be in low and one in very low condition.

Based on our understanding of current conditions, and after analysis of these future scenarios, increasing the redundancy of the species is the highest priority for this species to allow for its continued viability into the future. To accomplish this, establishment of at least one refugia population is needed.

FUTURE REPRESENTATION SUMMARY

Representation in the form of genetic or ecological diversity is important in maintaining the ability of the Three Forks springsnail to adapt to future environmental change. From our understanding of the current conditions and life history of the species, genetic and ecological representation is extremely low. Genetic representation for the Three Forks springsnail is limited to our current understanding that the different complexes have some genetic distance between haplotypes, but that all alleles found within the Boneyard Bog Complex were also found in the Three Forks Complex. This indicates that any loss of any population, within any complex, could potentially negatively impact the representation of rarer haplotypes. Conversely, any augmentation of populations or establishment at population-sites would increase representation is and potentially increase the representation of those rarer haplotypes.

Under future Scenario 1, in which current stressor trends continue and there are no additional conservation measures, there is an expected loss of representation across the species' range. This loss would be evidenced by only two populations being in moderate condition, with the other populations being either extirpated or in very low condition (20, and 1 respectively).

Under future Scenario 2, in which current stressor trends continue but there are additional and assumed successful conservation measures, representation is expected to be maintained, with one population being high condition, 16 in moderate condition, and seven in low condition.

Under future Scenario 3, in which current stressors and climate change effects increase, but where there are additional and assumed successful conservation measures, representation is still expected to be maintained, with 13 populations in moderate condition, and 10 in low condition. Under this scenario there are no populations in high condition.

Under future Scenario 4, in which current stressors and climate change effects increase and where there are no additional conservation measures, there is an expected loss of representation across the species' range. This loss would be seen by only three populations remaining extant, of which two would be in low and one in very low condition, resulting in a high extinction risk for the species.

Based on our understanding of current conditions, and after analysis of these future scenarios, increasing the redundancy of the species, rather than managing for specific alleles, should be a priority for this species given the current conditions.

Literature Cited

Arizona Game and Fish Department (AZGFD). 2022. Arizona Wildlife Conservation Strategy: 2022-2032. Page 393. Arizona Game and Fish Department.

Allen-Diaz, B., R. D. Jackson, J. W. Bartolome, K. W. Tate, and L. G. Oates. 2004. Long-term grazing study in spring-fed wetlands reveals management tradeoffs. California Agriculture 58:144–148.

Arora, V. K., and G. J. Boer. 2001. Effects of simulated climate change on the hydrology of major river basins. Journal of Geophysical Research: Atmospheres 106:3335–3348.

Avery, C. C., and E. S. Soles. 2003. Hydrological assessment of a wet meadow and perennial headwater stream in the White Mountains. Page 131. Final Report, Northern Arizona University, Flagstaff, Arizona, United States.

Brusca, R. C., and G. J. Brusca. 1990. Invertebrates. Sinauer Associates Inc., Sunderland, Masssachusetts, United States.

Calfee, R. D., and E. E. Little. 2003. The effects of ultraviolet-B radiation on the toxicity of fire-fighting chemicals. Environmental Toxicology and Chemistry 22:1525–1531.

California Department of Fish and Wildlife. California's Invaders: New Zealand Mudsnail. https://wildlife.ca.gov/Conservation/Invasives/Species/Nzmudsnail. Accessed April 13, 2023.

Corell, S. W. 1996. Groundwater Flow Model Scenarios of Future Groundwater and Surface Water Conditions: Sierra Vista Subwatershed of the Upper San Pedro Basin-Southeastern Arizona. Page 31. Technical Report, Arizona Department of Water Resources.

Creed, R. P. 1994. Direct and indirect effects of crayfish grazing in a stream community. Ecology 75:2091–2103.

Dai, A., T. Zhao, and J. Chen. 2018. Climate Change and Drought: Precipitation and Evaporation Perspective. Current Climate Change Reports 4: 301–312.

Dundee, D. S., P. H. Phillips, and J. D. Newsom. 1967. Snails on migratory birds. Nautilus 80:89–91.

Ebel, B. A., J. A. Moody, and D. A. Martin. 2012. Hydrologic conditions controlling runoff generation immediately after wildfire. Water Resources Research 48:1–13.

Erman, N. A. 2002. Lessons from a Long-term Study of Springs and Spring Invertebrates (Sierra Nevada, California, U.S.A.) and Implications for Conservation and Management. Page 13 Spring-Fed Wetlands: Important Scientific and Cultural Resources of the Intermountain Region. Desert Research Institute.

Fernandez, P. J., and P. C. Rosen. 1996. Effects of the introduced crayfish *Orconectes virilis* on native aquatic herpetofauna in Arizona. Pages 1–82. Final Report, Arizona Game and Fish Department, Phoenix, Arizona, United States.

Folsom, M. A., and J. A. Sorensen. 2018. Kingman Springsnail Survey Results 2005-2017. Page 18. Technical Report, Arizona Game and Fish Department.

Funkhouser, C. 2014, May. Captive propagation techniques for an endangered species of freshwater snail from a West Texas spring. Master's Thesis, Texas Tech University, Lubbock, Texas, United States.

Gaikowski, M. P., S. J. Hamilton, K. J. Buhl, S. F. McDonald, and C. H. Summers. 1996. Acute toxicity of three fire-retardant and two fire-suppressant foam formulations to the early life stages of rainbow trout (*Oncorhynchus mykiss*). Environmental Toxicology and Chemistry 15:1365–1374.

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom. 2014. Chapter 20: Southwest. Climate Change Impacts in the United States: the Third National Climate Assessment. Pages 462–486 *in* J. M. Melillo, T. (T. C.) Richmond, and G. W. Yohe, editors. Climate change impacts in the United States: The third National Climate Assessment. U.S. Global Change Research Program.

Guenther, H., K. Smith, T. Carr, and S. Fabritz-Whitney. 2009. Arizona Water Atlas Volume 5 – Central Highlands Planning Area 5:368.

Hammill, E., R. S. Wilson, and I. A. Johnston. 2004. Sustained swimming performance and muscle structure are altered by thermal acclimation in male mosquitofish. Journal of Thermal Biology 29:251–257.

Hanson, J. M., P. A. Chambers, and E. E. Prepas. 1990. Selective foraging by the crayfish *Orconectes virilis* and its impact on macroinvertebrates. Freshwater Biology 24:69–80.

Hasan, M. M., C. Strong, A. K. Kochanski, S. J. Burian, and M. E. Barber. 2020. Validating Dynamically Downscaled Climate Projections for Mountainous Watersheds Using Historical Runoff Data Coupled with the Distributed Hydrologic Soil Vegetation Model (DHSVM). Water 12:1389.

Herbst, D. B., M. T. Bogan, and R. A. Lusardi. 2008. Low specific conductivity limits growth and survival of the New Zealand mud snail from the Upper Owens River, California. Western North American Naturalist 68:324–333.

Hershler, R. 1994. A review of the North American freshwater snail genus *Pyrgulopsis* (Hydrobiidae). Pages 1–124. Smithsonian Institution Press, Washington, DC, United States.

Hershler, R. 1995, October 30. Hershler Response to Myers's 1995 Letter. Confirmation letter.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. The Veliger 41:14.

Hershler, R., and J. J. Landye. 1988. Arizona Hydrobiidae (Prosobranchia: Rissoacea). Pages 1–72. Smithsonian Institution Press, Washington D. C.

Hershler, R., and W. F. Ponder. 1998. A review of morphological characters of Hydrobioid snails. Pages 1–55. Smithsonian Institution Press, Washington, DC, United States.

Hershler, R., and D. W. Sada. 2002. Biogeography of Great Basin aquatic snails of the Genus *Pyrgulopsis*. Pages 255–256 Great Basin Aquatic Systems History. Smithsonian Institution Press, Washington, DC, United States.

Hershler, R., H.-P. Liu, and J. Howard. 2014. Springsnails: a new conservation focus in western North America. BioScience 64:693–700.

Hershler, R., H.-P. Liu, and L. E. Stevens. 2016. A New Springsnail (Hydrobiidae: *Pyrgulopsis*) from the Lower Colorado River Basin, Northwestern Arizona. Western North American Naturalist 76:72–81.

Hershler, R. and H.-P. Liu. 2017. Annotated Checklist of Freshwater Truncatelloidean Gastropods of the Western United States, with an Illustrated Key to the Genera. Technical Note 449. U.S. Department of the Interior, Bureau of Land Management, National Operation Center, Denver, Colorado.

Hurt, C. R. 2004. Genetic divergence, population structure and historical demography of rare springsnails (*Pyrgulopsis*) in the lower Colorado River basin. Molecular Ecology 13:1173–1187.

Hurt, C., and P. Hedrick. 2003. Genetic Variation in Arizona springsnails. Pages 1–35. Final Report, Arizona Game and Fish Department, Phoenix, Arizona, United States.

Hurt, C., and P. Hedrick. 2007. Conservation genetics of Arizona springsnails: identifying management units and regions of endemism. Pages 1–36. Heritage Grant Report, Arizona State University, Phoenix, Arizona, United States.

Ice, G., D. Neary, and P. Adams. 2004. Effects of wildfire on soils and watershed processes. Journal of Forestry 102:16–20.

Johnson, S. G. 2005. Age, phylogeography and population structure of the microendemic banded spring snail, *Mexipyrgus churinceanus*. Molecular Ecology 14:2299–2311.

Johnson, W. P., J. S. Beauchamp, M. J. Butler, and J. I. Sanchez. 2022. Successful establishment of endangered springsnails following habitat enhancement and translocations. Aquatic Conservation: Marine and Freshwater Ecosystems 32:1249–1262.

Jones, J. W., R. J. Neves, and E. M. Hallerman. 2012. Population performance criteria to evaluate reintroduction and recovery of two endangered mussel species, *epioblasma brevidens* and *epioblasma capsaeformis* (Bivalvia: Unionidae). Freshwater Mollusk Biology and Conservation 15:27.

Landye, J. J. 1973. Status of the inland aquatic and semi-aquatic mollusks of the American Southwest. Pages 1–64. Status Report, Lower Colorado River Basin Research Laboratory, Tempe, Arizona, United States.

Larson, M. D., J. C. Dewey, and A. C. Krist. 2020. Invasive *Potamopyrgus antipodarum* (New Zealand mud snails) and native snails differ in sensitivity to specific electrical conductivity and cations. Aquatic Ecology 54:103–117.

Lavretsky, P., E. Duenez, and J. Sorensen. 2021. Population genetics and conservation of recently discovered springsnails in Arizona. Journal of Molluscan Studies 87:8.

Van Leeuwen, C. H. A., and G. van der Velde. 2012. Prerequisites for flying snails: external transport potential of aquatic snails by waterbirds. Freshwater Science 31:963–972.

Little, E., and R. Calfee. 2002. Environmental persistence and toxicity of fire-retardant chemicals, Fire-Trol® GTS-R and Phos-Chek® D75-R to Fathead Minnows. Pages 1–52. Final Report, U.S. Geological Survey, Columbia Environmental Research Center, Columbia, Missouri, United States.

Lodge, D. M., M. W. Kershner, J. E. Aloi, and A. P. Covich. 1994. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. Ecology 75:1265–1281.

Lodge, D. M., and J. G. Lorman. 1987. Reductions in submersed macrophyte biomass and species richness by the crayfish *Orconectes rusticus*. Canadian Journal of Fisheries and Aquatic Sciences 44:591–597.

Longley, P. 2017, May. Quantifying the effects of changing snowpack dynamics on hydrologic partitioning at multiple spatial scales. Master's Thesis, University of Nevada, Reno, Nevada, United States.

Loughman, Z. J., and S. A. Welsh. 2013. Conservation Assessment and Atlas of the Crayfishes of West Virginia. Page 71. Final Report, West Virginia Division of Natural Resources.

Lysne, S. J., L. A. Riley, and W. H. Clark. 2007. The life history, ecology, and distribution of the Jackson Lake springsnail (*Pyrgulopsis robusta*). Journal of Freshwater Ecology 22:647–653.

Lysne, S., and P. Koetsier. 2006. Growth rate and thermal tolerance of two endangered snake river snails. Western North American Naturalist 66:230–238.

Lysne, S., and P. Koetsier. 2008. Comparison of desert valvata snail growth at three densities of the invasive New Zealand mudsnail. Western North American Naturalist 68:103–106.

Martinez, A. J., and J. Sorensen. 2016. Summary of conservation activities and survey data for Three Forks springsnail (*Pyrgulopsis trivialis*). Pages 1–31. Technical Report, Nongame and Endangered Wildlife Program, Arizona Game and Fish Department, Phoenix, Arizona, United States.

Martinez, M. A., and T. L. Myers. 2008. Associations between aquatic habitat variables and *Pyrgulopsis trivialis* presence/absence. Journal of Freshwater Ecology 23:189–194.

Martinez, M. A., and D. L. Rogowski. 2011. Use and apparent partitioning of habitat by an imperiled springsnail (Hydrobiidae) and a cosmopolitan pond snail (Physidae). The Southwestern Naturalist 56:216–223.

Martinez, M. A. 2009. Population Size Estimates for *Pyrgulopsis trivialis* (Hydrobiidae), an Imperiled Aquatic Snail from East-Central Arizona. Journal of the Arizona-Nevada Academy of Science 41:30–33.

Martinez, M. A., and J. A. Sorensen. 2007. Effect of sampling without replacement on isolated populations of endemic aquatic invertebrates in Central Arizona. Journal of the Arizona-Nevada Academy of Science 39:28–32.

Mladenka, G. C., and G. W. Minshall. 2001. Variation in the life history and abundance of three populations of Buneau Hot Springs springsnails. Western North American Naturalist 61:9.

Moody, J. A., and B. A. Ebel. 2012. Hyper-dry conditions provide new insights into the cause of extreme floods after wildfire. Catena 93:58–63.

Myers, T. L. 1995a, October 19. Arizona Game and Fish HDMS card for Boneyard Creek springsnail specimen.

Myers, T. L. 1995b, October 23. Myers Letter to Hershler with Specimens. Enclosure letter.

Myers, T. L. 2000, January 7. Myers Letter to Martinez on Crayfish at Three Forks. Crayfish Status Report.

Myers, T. L. 2011. Summary of Field Inspection of Boneyard Creek, 27-28 April 2011, and 04 May 2011, including Sierra Blanca Ranch and the downstream end of Boneyard Bog. Pages 1–41. Site Report.

Myers, T. L. 2018. Brief summary of the historical and current occupancy of springs by Three Forks springsnails as of February 28, 2018. Page 7. Site Report.

Myers, T. L., and A. Varela-Romero. 2012. Taxonomic validation and population structure analysis of *Pyrgulopsis* populations from the upper Black River, Arizona (*P. trivialis*) and from the upper Rió San Bernardino, Arizona and Sonora (*P. 95ou95ardina*). Pages 1–54. Final Report, Arizona Ecological Services, Region 2 (Southwest), U.S. Fish and Wildlife Service, Phoenix, Arizona, United States.

Norris, L. A., and W. L. Webb. 1989. Effects of Fire Retardant on Water Quality. Pages 79–86. Technical Report, U.S. Department of Agriculture, Forest Service.

Oliver, D., A. Loubere, and J. Sorensen. 2021. Efficacy of low-dose EarthTec® QZ treatment for the control of New Zealand mud snails *Potamopyrgus antipodarum* in a hatchery environment. Management of Biological Invasions 12:85–95.

Pagowski, V. A., and J. A. Sorensen. 2018. Verde Rim Springsnail Survey Results, 2017-2018. Page 20. Technical Report, Arizona Game and Fish Department.

Parise, M., and S. H. Cannon. 2012. Wildfire impacts on the processes that generate debris flows in burned watersheds. Natural Hazards 61:217–227.

Pearson, D., S. Wells, T. Sprankle, J. Sorensen, and M. Martinez. 2014. Reproductive Seasonality and Developmental Characteristics of the Page Springsnail (*Pyrgulopsis morrisoni*). Journal of the Arizona-Nevada Academy of Science 45:64–69.

Pennak, R. W. 1989. Fresh-water invertebrates of the United States: Protozoa to Mollusca. 3. Ed. John Wiley & Sons, Inc, New York, New York, United States.

PHOS-CheK Environmental and Toxicology Safety. 2009. ICL Performance Products LP.

Pianka, E. R. 1970. On r- and K-Selection. The American Naturalist 104:592–597.

Piorkowski, M. D., and J. M. Diamond. 2015. Springsnails on Department of Defense installations in the desert Southwest: identification, status, and distribution of at-risk springsnail communities. Page 92. Final Report, Arizona Game and Fish Department, Phoenix, Arizona, United States.

Pörtner, H.-O., D. C. Roberts, M. M. B. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, and B. Rama, editors. 2022. Summary for policymakers. Page Climate Change 2022: Impacts, Adaptation and Vulnerability.

Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Reidmiller, D. R., C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, T. K. Maycock, and B. C. Stewart. 2018. Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program.

Riley, L. A., M. F. Dybdahl, and R. O. Hall. 2008. Invasive species impact: asymmetric interactions between invasive and endemic freshwater snails. Journal of the North American Benthological Society 27:509–520.

Roccaforte, J. P. 2013. The Wallow Fire and its effects on mixed conifer forest: a comparison with reference conditions. Pages 1–17. Technical Report, Ecological Restoration Institute, Northern Arizona University, Flagstaff, Arizona, United States.

Roscoe, E. J. 1955. Aquatic snails found attached to feathers of white-faced glossy ibis. The Wilson Bulletin 67:66–67.

Sada, D. W. 2007. Synecology of a springsnail (Caenogastropoda: Hydrobiidae) assemblage in a western U.S. thermal spring province. The Veliger 50:59–71.

Seneviratne, S. I., N. Nicholls, D. Easterling, C. M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, X. Zhang, M. Rusticucci, V. Semenov, L. V. Alexander, S. Allen, G. Benito, T. Cavazos, J. Clague, D. Conway, P. M. Della-Marta, M. Gerber, S. Gong, B. N. Goswami, M. Hemer, C. Huggel, B. van den Hurk, V. V. Kharin, A. Kitoh, A. M. G. K. Tank, G. Li, S. Mason, W. McGuire, G. J. van Oldenborgh, B. Orlowsky, S. Smith, W. Thiaw, A. Velegrakis, P. 96ou, T. Zhang, T. Zhou, and F. W. Zwiers. 2012. Changes in climate extremes and their impacts on the natural physical environment. Pages 109–230 *in* C. B. Field, V. Barros, T. F. Stocker, and Q. Dahe, editors. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. First edition. Cambridge University Press, Cambridge, United Kingdom.

Singleton, M. P., A. E. Thode, A. J. Sánchez Meador, and J. M. Iniguez. 2019. Increasing trends in high-severity fire in the southwestern USA from 1984 to 2015. Forest Ecology and Management 433:709–719.

Smith, D. R., N. L. Allan, C. P. McGowan, J. A. Szymanski, S. R. Oetker, and H. M. Bell. 2018. Development of a Species Status Assessment Process for Decisions under the U.S. Endangered Species Act. Journal of Fish and Wildlife Management 9:302–320.

Southwood, T. R. E., R. M. May, M. P. Hassell, and G. R. Conway. 1974. Ecological Strategies and Population Parameters. The American Naturalist 108:791–804.

Sorensen, J. A. 2022. Springsnail Survey and Monitoring Protocols- Updated 2022. Page 21. Technical Report, Arizona Game and Fish Department, Phoenix, Arizona, United States.

Sorensen, J. A. 2021. Page Springsnail and Three Forks Springsnail Baseline Surveys of 2001 and 2002. Page 22. Technical Report, Arizona Game and Fish Department.

Sorensen, J. A., and S. Lerich. 2015. Turkeys, Snails and Crayfish…oh my! Albuquerque, New Mexico, United States.

Starrett, G. 2004. Dissolved Oxygen Fact Sheet. The Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment. State Water Resources Control Board. 5 pp.

Stevens, Z. T., and B. M. Poynter. 2019. Huachuca Springsnail Program Synopsis. Page 6. Annual Report, Arizona Center for Nature Conservation- Phoenix Zoo.

Taylor, D. W. 1987. Fresh-water mollusks from New Mexico and vicinity. Pages 1–52. New Mexico Bureau of Mines & Mineral Resources, Socorro, New Mexico, United States.

U.S. Environmental Protection Agency (EPA). 2021. A closer look: temperature and drought in the Southwest. Government Website. https://www.epa.gov/climate-indicators/southwest.

U.S. Fish and Wildlife Service (USFWS). 2011. Endangered and threatened wildlife and plants; Listing and Designation of Critical Habitat for the Three Forks springsnail and San Bernardino springsnail. Federal Register 76:71300–71307.

U.S. Fish and Wildlife Service (USFWS). 2012. Endangered and threatened wildlife and plants; determination of endangered status for Three Forks springsnail and threatened status for San Bernardino springsnail throughout their ranges and designation of critical habitat for both species. Federal Register 77:34.

U.S. Fish and Wildlife Service (USFWS). 2015. Species Status Assessment Report for the Page Springsnail. Page 77. Species Status Assessment, Region 2 (Southwest), U.S. Fish and Wildlife Service, Albuquerque, New Mexico, United States.

U.S. Fish and Wildlife Service (USFWS). 2016. SSA Framework version 3.4:21.

U.S. Fish and Wildlife Service (USFWS). 2021. Accomplishment Report: July 2021. Pages 1–4. Accomplishment Report, Arizona Fish and Wildlife Conservation Office, U.S. Fish and Wildlife Service, Flagstaff, Arizona, United States.

U.S. Forest Service (USFS). 2007. Wildland fire chemical products toxicity and environmental concerns: general information. U.S. Department of Agriculture, Forest Service.

U.S. Forest Service (USFS). 2019. Implementation guide for aerial application of fire retardant. Pages 1–91. Implementation Guide, U.S. Department of Agriculture, Forest Service, Fire and Aviation Management, Washington, DC, United States.

U.S. Forest Service (USFS). Wildland Fire Chemical Systems - National Technology and Development Program - USDA Forest Service. https://www.fs.usda.gov/rm/fire/wfcs/wildland-fire-chemicals.php. Accessed December 15, 2022.

Webb, J. K., B. W. Brook, and R. Shine. 2002. What makes a species vulnerable to extinction? Comparative life-history traits of two sympatric snakes: Life histories of two sympatric snakes. Ecological Research 17:59–67.

Wells, S., D. Pearson, T. Sprankle, J. Sorensen, and M. Martinez. 2012. Ex- situ husbandry and environmental parameters resulting in reproduction of the Page springsnail, *Pyrgulopsis morrisoni*: implications for conservation. Journal of the Arizona-Nevada Academy of Science 44:69–77.

Wesselingh, F. P., G. C. Cadée, and W. Renema. 1999. Flying high: on the airborne dispersal of aquatic organisms as illustrated by the distribution histories of the gastropod genera Tryonia and Planorbarius. Geologie en Mijnbouw 78:165–174.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313:940–943.

Yang, Y., R. Chen, G. Liu, Z. Liu, and X. Wang. 2022. Trends and variability in snowmelt in China under climate change. Hydrology and Earth System Sciences 26:305–329.