Species Status Assessment for Nine springsnails of Ash Meadows and the Amargosa Valley

Kings Pool, Ash Meadow National Wildlife Refuge

Version 1.0
U.S. Fish and Wildlife Service
Southern Nevada Field Office
Interior Region California-Great Basin
January 2021

Contributing Authors: Michael Schwemm

ACKNOWLEDGEMENTS

We thank all conservation partners who contributed to this Species Status Assessment. We recognize and thank the following individuals who provided substantive review and insights for our Species Status Assessment as peer and partner agency reviewers: Eric Miskow, Donald Sada, Larry Stevens, Megan Poff, Tracie Jackson, Corey Lange, and Kevin Wilson. We also thank all Fish and Wildlife Service personnel from Interior Region 8 who contributed to the Species Status Assessment; in particular, we acknowledge the contributions of the other members of the U.S. Fish and Wildlife Service core team: Corey Kallstrom, Heidi Crowell, Dan Russell, Glen Knowles, and Bradd Bridges.

In addition, we thank the following individuals whose efforts provided substantive data used in this report: Donald Sada (Desert Research Institute), John Umek (Desert Research Institute), Kevin Guadalupe and others with the Nevada Department of Wildlife, Geoff Moret and Erin Orozco with the United States Geological Survey, and Corey Lee and others at Ash Meadows National Wildlife Refuge.

Lastly, special thank you to those landowners who permitted surveyors to access their property to survey and collect information on springs and springsnails.

Cover photograph by Daniel Villanueva (Student Conservation Association for the U.S. Fish and Wildlife Service).

SUGGESTED CITATION: U.S. Fish and Wildlife Service. 2021 (January). Species Status Assessment Report for Nine Springsnails of Ash Meadows and the Amargosa Valley Nevada, Version 1.0. U.S. Fish and Wildlife Service, Southern Nevada Field Office. 131 pp.

Table of Contents

EXECUTIVE SUMMARY 6
ABBREVIATIONS AND ACRONYMS 14
GLOSSARY OF TERMS 16
1.0 Introduction 18
1.1 State Listing Status 19
2.0 Analysis Framework 19
2.1 Analysis Area 19
2.2 SSA Framework 21
2.3 Methodology 22
3.0 Species Ecology and Resource Needs 26
3.1 Springsnail Biogeography, Biology, and Habitat 26
3.1.1 Range and Distribution 26
3.1.2 Biology and Life History 26
3.2 Spring Characteristics and Function 32
3.3 Physical and Biological Needs of Springsnails 35
3.3.1 Water Quality 36
3.3.2 Aquatic Vegetation and Substrate 37
3.3.3 Free-Flowing Water 38
3.3.4 Adequate Spring Discharge 39
3.4 Unknowns 39
4.0 Factors That May Influence Species Needs 39
4.1 Hydrology and Water Management Considerations 39
4.1.1 Hydrology 39
4.1.2 Water Management 41
4.2 Threats Considered But Not Carried Forward 43
4.2.1 Parasitism and Disease 44
4.2.2 Collection 44
4.3 Threats Carried Forward 44
4.3.1 Predation and Competition 45
4.3.2 Vegetation and Soil Disturbance 47

4.3.2 Water Pollution 48
4.3.3 Spring Modifications 49
4.4 Land Management and Conservation Plans 62
4.5 Summary 62
5.0 Current Conditions—Springsnail Habitats and Species Viability 63
5.1 Amargosa Desert Hydrographic Area (230) – Springs and Spring Provinces and Current Habitat Condition 63
5.1.1 Kings Pool (Ash Meadows NWR) 63
5.1.2 Point of Rocks Spring Province (Ash Meadows NWR) 64
5.1.3 Big Spring (Ash Meadows NWR) 65
5.1.4 Chalk Spring (Ash Meadows NWR) 65
5.1.5 Collins Ranch Spring (Ash Meadows NWR) 66
5.1.6 North of Collins Ranch Springs (Ash Meadows NWR) 66
5.1.7 Crystal Spring (Ash Meadows NWR) 67
5.1.8 Fairbanks Springs (Ash Meadows NWR) 67
5.1.9 Five Springs Province (Ash Meadows NWR) 68
5.1.10 Last Chance Spring (Ash Meadows NWR) 68
5.1.11 South of Clay Pits Spring (Private) 68
5.1.12 Marsh Spring (Ash Meadows NWR) 69
5.1.13 Mary Scott Spring (Ash Meadows NWR) 69
5.1.14 North Indian Spring (Ash Meadows NWR) 70
5.1.15 South Indian Spring (Ash Meadows NWR) 70
5.1.16 North Scruggs Spring (Ash Meadows NWR) 71
5.1.17 South Scruggs Spring (Ash Meadows NWR) 71
5.1.18 School Spring (Ash Meadows NWR) 72
5.1.19 Near Crystal Reservoir (Ash Meadows NWR) 72
5.1.20 Devils Hole (Death Valley National Park) 72
5.1.21 Shoshone Spring (Shoshone, CA) 73
5.1.22 Unnamed Spring near Tecopa (Tecopa, CA) 73
5. 2 Summary of Current Conditions by Species 73
5.2.1 Amargosa tryonia (Tryonia variegata) 73
5.2.2 Ash Meadows pebblesnail (Pyrgulopsis erythropoma) 74
5.2.3 Crystal springsnail (Pyrgulopsis crystalis) 75

5.2.4 Fairbanks springsnail (Pyrgulopsis fairbankensis) 75
5.2.5 Point of Rocks tryonia (Tryonia elata) 76
5.2.6 Distal-gland springsnail (Pyrgulopsis nanus) 76
5.2.7 Median-gland springsnail (Pyrgulopsis pisteri) 77
5.2.8 Minute tryonia (Tryonia ericae) 77
5.2.9 Sportinggoods tryonia (Tryonia angulata) 78
5.3 Unknowns/Uncertainties 79
6.0 Potential Future Conditions – Species Viability 79
6.1 Consideration for Springsnail 3Rs 80
6.2 Future Scenarios 82
6.2.1 Scenario 1: Springs maintain springflow or discharge similar to current conditions. 82
6.2.2 Scenario 2: Springs experience some reduction in springflow or discharge. 83
6.2.3 Scenario 3: Springs experience a significant reduction in springflow or discharge, or completely eliminated. Flow and discharge are inadequate. 84
6.3 Future Condition Species Summaries for 3Rs 84
6.3.1 Amargosa Tryonia (Tryonia variegata) 84
6.3.2 Ash Meadows Pebblesnail (Pyrgulopsis erythropoma) 86
6.3.3 Crystal Springsnail (Pyrgulopsis crystalis) 87
6.3.4 Fairbanks Springsnail (Pyrgulopsis fairbankensis) 88
6.3.5 Point of Rocks Tryonia (Tryonia elata) 89
6.3.6 Distal-gland Springsnail (Pyrgulopsis nanus) 90
6.3.7 Median-gland Springsnail (Pyrgulopsis pisteri) 91
6.3.8 Minute Tryonia (Tryonia ericae) 92
6.3.9 Sportinggoods Tryonia (Tryonia angulata) 93
6.4 Cumulative Effects 93
7.0 Status Assessment Summary 94
References Cited 97
APPENDIX A: Current Management and Conservation Measures 111
APPENDIX B: Survey Data and Threat Evaluation for Springs Supporting Nine Springsnails Species in this SSA Report. 121

EXECUTIVE SUMMARY

This report summarizes the results of a species status assessment (SSA) for nine aquatic springsnail species (listed below). This report is intended to provide a summary of the current understanding of the biological status of the nine springsnail species. This SSA report does not represent a decision by us, the U.S. Fish and Wildlife Service (Service), whether or not to list the species under the Endangered Species Act (Act).

- Amargosa tryonia (*Tryonia variegata*)
- Ash Meadows pebblesnail (*Pyrgulopsis erythropoma*)
- Crystal springsnail (*Pyrgulopsis crystalis*)
- Fairbanks springsnail (*Pyrgulopsis fairbankensis*)
- distal-gland springsnail (*Pyrgulopsis nanus*)
- median-gland springsnail (*Pyrgulopsis pisteri*)
- minute tryonia (*Tryonia ericae*)
- Point of Rocks tryonia (*Tryonia elata*)
- sportinggoods tryonia (*Tryonia angulata*)

All nine species addressed in this SSA are endemic to a small number of springs and spring provinces in southern Nevada and California. All nine species occur in the lower Amargosa Valley, on the Ash Meadows National Wildlife Refuge (NWR) (Nye County, Nevada), and immediately nearby on Federal and private lands. One species, the Amargosa tryonia, also occurs historically at two springs 40 kilometers (km) (25 miles (mi)) further downstream within the Amargosa River drainage.

To evaluate the biological status of these species, both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). Resiliency is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature or rainfall), periodic disturbance within the normal range of variation (e.g., fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity). Redundancy is the ability of a species to withstand catastrophes (i.e., stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely). Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. Together, the 3Rs, and their core autecological parameters of abundance, distribution and diversity, comprise the key characteristics that contribute to a species' viability, its ability to sustain populations in the wild over time. When combined across populations, they measure the health of the species as a whole.

Historically and through the present, springs and the biological needs of each springsnail species have been negatively impacted to varying degrees by multiple threats, including predation and competition, vegetation and soil disturbance, spring modification, and groundwater pumping. Sources of these threats include invasive, nonnative, and native species; roads; wildfire; grazing and browsing by ungulates; recreation; herbicides, and human development. Primary among these has been the historical effects of groundwater pumping associated with agricultural development in the 1970s, the degree of which are now prohibited under current water management.

In many cases, these impacts result in short-term declines to a species' population(s). In some instances, the habitat or the biological needs of a species may have been affected to the point where a population's distribution is restricted, or a population of the species is lost. While these threats may continue to affect populations to some extent in the future despite a variety of ongoing conservation measures at some locations, this analysis considers the most likely threats to impact future conditions are habitat modification from groundwater pumping and diversion, and changing climate conditions that result in altered precipitation. These threats directly and indirectly affect springflow or discharge.

Based on our understanding of historical, current, and probable future conditions, we developed three scenarios to assess the 3Rs over the next 50 years. This timeframe is based on our balancing a reasonably long-term future for the species—incorporating the biology of springsnails, along with our confidence in estimating future habitat changes relating to such factors as hydrology, climate change, groundwater management, and species recovery efforts. While we expect free-flowing water and adequate spring discharge to be the main biological and physical needs potentially affected, such reductions may also impact the amount of suitable vegetation and substrate available, among other parameters. The following three scenarios are not exhaustive, but chosen to represent a range of possible outcomes from the current condition to those of extreme reductions in springflow, each with increasing risk to species viability. The three scenarios considered in this report are:

1) Springs maintain springflow or discharge similar to current conditions;
2) Springs experience slight to moderate reductions in springflow or discharge;
3) Springs experience extreme reductions in springflow or discharge, or springflow or discharge are completely eliminated (i.e., springflow and discharge are inadequate).

To evaluate these scenarios, we considered how each would affect the resiliency, redundancy, and representation of each springsnail species. Resiliency is measured based on metrics of population health, such as the size and growth rate of populations and how quickly they are able to rebound in numbers after an event results in loss of individuals or populations. Because springsnail information on these metrics is limited, we assessed springsnail resiliency by taking into consideration their apparently high fecundity rates, ability to withstand past disturbances, current conditions of springs and spring provinces, length of occupied habitat, and beneficial recovery efforts for the species. To assess springsnail redundancy, we factored in the number of populations for each species, the distance between populations, and whether each species has populations sufficiently distributed across its range. Or in other words, we considered populations that occur with landscape features that provide physical separation between populations (e.g., distinct springbrooks with demographic independence). Representation is measured through ecological diversity (environmental variation) and genetic diversity within and among populations. Because information is lacking or limited for these springsnail species, we assume a species with greater diversity of environmental conditions or geographic isolation has higher representation. In particular, we considered differences in elevation, habitat variability, geographic distance, and flow rates within and among populations.

In *Scenario 1*, adequate springflow and discharge would be similar to current conditions, so resiliency, redundancy, and representation are not expected to be significantly affected in this future scenario. We anticipate springsnails would maintain their current levels of resiliency. *Scenario 1* likely requires the maintenance of groundwater protections enforced by water resource agencies. Additionally, impacts to springsnail habitat from stochastic events, particularly on Federal lands, are expected to be repaired through habitat restoration and reintroduction efforts, if needed. Even with adequate spring discharge, populations may be extirpated if stochastic events are severe enough, and restoration activities do not or cannot occur. Redundancy and representation would remain similar to current conditions. The predicted viability of species in *Scenario 1* is expected to equate to viability estimated in the current condition, and provides comparatively low risk relative to future *Scenarios 2* and *3*.

A slight to moderate reduction in springflow due to groundwater pumping and/or climate change is characterized by *Scenario 2*. The level of impact to resiliency, redundancy, and representation would vary greatly among species, largely based on current conditions of the biological and physical conditions at the springs, number of populations per species, and the present level of discharge at each spring. With respect to some reduction in spring discharge, this scenario predicts that habitats of low flow at present would be increasingly affected relative to large spring habitats.

In *Scenario 3*, springflow and discharge would be extremely reduced or eliminated completely, so resiliency, redundancy, and representation would all be affected by these future conditions. For many springsnail species, entire populations would be affected and potentially extirpated because three of the four physical and biological needs would not be adequate. This scenario is plausible in the absence of water management and other habitat conservation actions. If entire populations are eliminated, species viability will be reduced. Species represented by few populations are at greater risk of extirpation.

In order to determine the status of the nine springsnail species for this report, we conducted surveys to determine their present distribution, predominantly occurring in years 2018 and 2020. Springsnail abundance and distribution fluctuates seasonally, and accurately determining species status requires numerous site visits, and contributes to uncertainly in this report. In general, the current condition for the nine springsnail species considered here show that each species remains extant, and occupies all or portions of the habitats in which they were originally described. Several species are site-specific and occur only within a single habitat, both historically and at present. For some species, several populations are reported dry or otherwise extirpated at present. As a group, these springsnails exhibit some resiliency despite past and present threats. With respect to extreme groundwater pumping that occurred during the 1970s (which continue to partially influence water levels today), springsnails occur at most sites despite historic low flow and dry conditions. However, because springsnail habitats are geographically and demographically discrete and differentially affected by hydrology and ecological threats, each population and the species of which composed, must be considered independently.

Based on projections of altered precipitation and temperature (Chapter 4.3, climate change) and our current understanding of ongoing groundwater withdrawal that might be expected with human population growth, each species will be discussed below as they pertain to probable impacts extending into the next 50 years. A summary table of species viability is presented in Table 7.1. The following information summarizes the historical, current, and probable future conditions for each species and their habitats.

Amargosa tryonia (*Tryonia variegata*)

The Amargosa tryonia was historically known to occur in at least 15 springs or spring provinces on the Ash Meadows NWR (NWR), one spring within Death Valley National Park, one spring immediately adjacent to the Refuge on private land, and two springs 40 km (25 mi) south of the Refuge in Inyo County, California. Historical impacts to the springs and spring provinces resulted from spring modifications, vegetation and soil disturbance from recreation or grazing/browsing ungulates, groundwater pumping and diversion, and invasive predatory and competitive species. This species currently occurs in at least 12 springs at present, including Kings Pool, Point of Rocks spring province, Collins Ranch Spring, Five Springs, Marsh Spring, Mary Scott Spring, North and South Indian springs, North and South Scruggs springs, School Spring, and Devils Hole. Of the many springs supporting this species, only two (Chalk and the North of Collins Ranch springs) are reported dry in the most recent survey. Although several historic sites off the Refuge reflect an unknown status with regard to this species, the regionally widespread distribution, number of populations, and abundance confer high level of species viability at present. The only major threat to this species in the future stems from drastic reduction in springflow. Even under extreme low discharge conditions, our most extreme future scenario expected with severe climatic change and/or increased groundwater pumping, many populations might avoid extirpation.

Ash Meadows pebblesnail (*Pyrgulopsis erythropoma*)

The Ash Meadows pebblesnail occurs at two springs, the large[1] Kings Pool and several smaller spring outflows of the Points of Rocks springs province, both in the area referred to as Points of Rocks. The entire species range spans a distance of only 200 meters (m) (650 feet (ft)). This *Pyrgulopsis* is common to abundant in recent surveys at both Kings Pool and at least three outflows at the Point of Rocks springs province. The species is both partially protected and impacted by disturbance from recreational visitors at the Refuge. The outflows supporting this species show little redundancy or representation, given that all individuals occupy the same general area. The populations at Kings Pool and at least three outflows of the Point of Rocks

[1] Descriptions for small, moderate, and large springs are provided in spring descriptions (Chapter 5).
[2] "pyrg" refers to any springsnail of the genus *Pyrgulopsis*

spring province are shown to be resilient since their description in 1987. The smallest outflows at Point of Rocks are easily impacted by over-growth of terrestrial vegetation (e.g., sawgrasses), potentially associated with disturbance or hydrologic changes. Given the past habitat restoration and protections afforded by the Ash Meadows NWR, these populations exhibit some resilience against future disturbance that could negatively affect substrate and vegetation, or impoundment. As such, the future threats for this species, if any, likely result from inadequate discharge. Overall, this species is characterized as one of moderate viability at present. Future scenarios with reductions is springflow are likely to decrease viability to low or elimination of the smallest outflows completely.

Crystal springsnail (*Pyrgulopsis crystalis*)
The Crystal springsnail is a site-specific pyrg[2], and is endemic to a single spring orifice at Crystal Spring, on the Ash Meadows NWR. As initially described, and at present, all individuals occur at the orifice of the deep spring pool. Relative abundance as measured by capture for this species is scarce, but capture bias is likely given logistical difficulties of free-diving within a high discharge spring. This species occupies a markedly small species range of 1 m^2 (~20 ft^2) in total, possibly the smallest area on the Refuge. As above for Kings Pool and Points of Rocks spring province, Crystal Spring is the main destination for Refuge visitors. The site is attached to the Visitor Center and Refuge headquarters, and is maintained in restored condition. The site supports nonnative fish and invertebrate predators, but otherwise the habitat is characterized as restored and protected from human disturbances. The present distribution, although exceptionally small, has not appreciably changed since the species was described, and with protections afforded by the Refuge has high resilience. However, because redundancy and representation are zero, the overall species viability is considered to be moderate. Future scenarios with minor reduction is springflow are unlikely to result in extirpation given the high discharge.

Fairbanks springsnail (*Pyrgulopsis fairbankensis*)
The Fairbanks springsnail is another site-specific pyrg, endemic to a single habitat at Fairbanks Spring on the north boundary of Ash Meadows NWR. As initially described, and at present, individuals occur at the orifice of the spring pool and extend downstream at least 1,000 m (3,280 ft). Relative abundance of the Fairbanks springsnail at present is abundant despite the presence of nonnative fish predators, invasive snails, and signs of historical and current impoundment. The site now appears stable, and supports the species in question. The present distribution, although subject to several threats, has not changed since the species was described, and seems resilient to human perturbation and invasive species. Given the combination of high resilience, with zero redundancy or representation yields an overall species viability of moderate. Given the high springflow at Fairbanks Spring, a reduction in springflow associated with *Scenario 2* or *Scenario 3* is unlikely to cause extirpation of the Fairbanks springsnail.

Distal-gland springsnail (*Pyrgulopsis nanus*)
The distal-gland springsnail is endemic to three springs in the central area of Ash Meadows NWR (Mary Scott Spring, Five Springs spring province and Collins Ranch Spring). Historically, the species occurred at a fourth spring now considered extirpated due to near-dry conditions (North of Collins Ranch Spring). Relative abundance of this pyrg is common, but not abundant,

at the three sites during recent surveys. Some site disturbance is present from ungulate use at Mary Scott Spring, and channel modification and invasive species (*Melanoides*) occur at Five Springs spring province. Collins Ranch Spring is notably low discharge, but lacks impacts of invasive species, and considerably improved by recent restoration activities. Resiliency is moderate for this species at all sites at present. The occurrence of all three sites in the same general area of the Refuge, with similar habitat characteristics categorize both redundancy and representation as moderate. Overall viability for current condition of this species is therefore moderate. However, the reduction in discharge in future scenarios might decrease species viability as a cumulative effect with invasive species in Five Springs and Mary Scott Spring, and directly via drought at Collins Ranch Spring. Thus, future *Scenarios 2* and *3* might reduce species viability to low or very low, respectively.

<u>Median-gland springsnail (*Pyrgulopsis pisteri*)</u>

The median-gland springsnail occurs at three springs in the central area of Ash Meadows: Marsh Spring, North Scruggs Spring, and School Spring. Their habitats are of similar size and the condition has been restored by the Refuge in recent years. Each spring is geographically and demographically independent, but geographically proximate. The small to moderate size of these springs make them vulnerable to drought, but otherwise in adequate condition to support springsnails. With relatively little geographic separation across three sites with little ecological similarity, this species is characterized by moderate redundancy, but low representation. The delicate nature and significant expense to previously remove invasive crayfish, and repair other site disturbances, has resulted in the highest level of biological security by the Refuge, and the prevention of public access by road. These conservation measures afford resilience against impacts unrelated to spring discharge, and this species is categorized with overall moderate viability in current condition. However, future drought/groundwater scenarios that reduce springflow with some reduction (*Scenario 2*), or extreme reduction (*Scenario 3*), will likely result in species viability changes to low and very low conditions, respectively.

<u>Minute tryonia (*Tryonia ericae*)</u>

The minute tryonia is described from only two spring habitats in close geographic proximity: North Scruggs Spring and the North of Collins Ranch Spring, both within the Ash Meadows NWR. The North Scruggs Spring habitat is restored, protected, and supports springsnails (see above, median-gland springsnail), however, the North of Collins Ranch site was recorded as dry (U.S. Geological Survey (USGS) 2018, unpubl., entire), or nearly so (Service 2020, unpubl., entire) for surveys conducted for this report. No significant impacts other than drought conditions and significant vegetation are noteworthy, and no springsnails were encountered during either survey at this site. It is unknown why the North of Collins Ranch Spring lacks adequate discharge, but may be the result of natural variation in vegetative growth, or changes in hydrology that resulted in extremely low discharge. At present this species has potentially lost 50 percent of its range (one of two sites), and is susceptible to drought conditions. The species-level viability is moderate given the protections afforded by the Refuge exclusive of water, but any further reductions in springflow, via natural variation, or as those defined for *Scenario 2* or *3* will decrease future viability to low or very low conditions.

Point of Rocks tryonia (*Tryonia elata*)

The distribution of the Point of Rocks tryonia is restricted to the Point of Rocks spring province, and does not occur in the nearby Kings Pool (see Ash Meadows pebblesnail). These outflows vary in discharge from seeps (outflows #38, #39 and #40), to small springs (#35, #36 and #37). Some of the markedly small seeps were recently reported as dry depending on seasonal influences and vegetation growth occurring at each survey. Additionally, *Tryonia* at Point of Rocks are scarce, as much of the habitat is better suited to endemic pyrgs, that occupy areas with less fine sediment. As the entire species with small population size occurs among several outflows at one general site [~200 m (650 ft) across in width], little redundancy and nearly no representation (e.g., no assumed genetic or ecological variation) are likely. However, given the past habitat restoration and protections afforded the Ash Meadows NWR, these populations exhibit partial (excluding spring discharge) resilience against future disturbance that potentially affect water quality, substrate and vegetation, or impoundment. Impacts from site disturbance from visitors is also minimal. Overall, the relative size of these springs (susceptibility to drought), combined with moderate resiliency afforded by conservation actions, and low redundancy and representation, classify species viability as moderate. However, reduced springflow in drier conditions defined in *Scenario 2* and *3* may result in lower viabilities.

Sportinggoods tryonia (*Tryonia angulata*)

The sportinggoods tryonia occurs at three geographically distinct springs (Fairbanks, Crystal, and Big springs), that comprise three of the four largest springs on the Ash Meadows NWR. This species is typically abundant or common at all three springs, both historically and at present. All sites sustain several ongoing threats due to past human development and invasive fish and invertebrates. Such large springs historically offered greater opportunity for human development, and Fairbanks and Big springs have water diversions and impoundments that remain to various degrees. Crystal Spring has been restored as a major destination for Refuge visitors, and is protected from pedestrian traffic via a boardwalk to the spring pool and channel. The population abundance at these sites suggest high resilience against threats for this species. The notable geographical separation of the three springs north to south, and assumed demographic and genetic isolation, suggest that these habitats support some interspecific variation, and offer both moderate redundancy and representation. Although the species occurs at only three springs, the size of habitat, resistance to threats and geographic distances among them confer high species-level viability in the current condition. The large discharge of these springs additionally afford protection against future reductions in discharge associated with *Scenario 2* or *3.* Even under extreme reduction in discharge or near elimination defined in the most extreme case, the species is likely to avoid extirpartion.

ABBREVIATIONS AND ACRONYMS

Acronym or Abbreviation	Full Name
°C	Degrees Celsius
°F	Degrees Fahrenheit
µS/cm	microsiemens per centimeter
3Rs	Resiliency, Redundancy, and Representation
BLM	Bureau of Land Management
CA	California
CDFW	California Department of Fish and Wildlife
CDWR	California Department of Water Resources
cfs	Cubic feet per second
cm/sec	Centimeters per second
CPOM	Coarse particulate organic matter
CPUE	Catch Per Unit Effort
CSI	Coyote Springs Investment, LLC
DCNR	Nevada Department of Conservation and Natural Resources
DO	Dissolved oxygen
EIS	Environmental Impact Statement
ESA	Endangered Species Act
FLPMA	Federal Land Policy and Management Act
ft	Foot or feet
g/min	Gallons per Minute
GCM	General circulation model
GIS	Geographic Information Systems
HA	Hydrographic Area
in	Inch(es)
In/sec	Inches per second
IPCC	Intergovernmental Panel on Climate Change
km	kilometers
L/min	Liters per minute
m	Meter(s)
mi	Miles
mm	Millimeter(s)
mg/L	Milligrams per liter
MGD	Million gallons per day
NCA	National Conservation Area
NDOW	Nevada Department of Wildlife
NDWP	Nevada Division of Water Planning
NEPA	National Environmental Policy Act of 1970

NRA	National Recreation Area
NSE	Nevada State Engineer
NP	National Park
NV	Nevada
NVE	Nevada Energy
NWR	National Wildlife Refuge
ppm	Parts per million
RMP	Resource Management Plan
Service	U.S. Fish and Wildlife Service
SMNRA	Spring Mountains National Recreation Area
SNWA	Southern Nevada Water Authority
sp. *or* spp.	Species
SSA	Species Status Assessment
TDS	Total Dissolved Solids
USGS	United States Geological Survey
USFS	United States Forest Service
WAP	Wildlife Action Plan
WCP	Wetland Conservation Plan
WMA	Wildlife Management Area
WSA	Wilderness Study Area

GLOSSARY OF TERMS

Term	Definition
abundant	Catch per unit effort greater than 20 individuals.
aquifer	Rock or sediment layer that contains and transmits groundwater.
alluvial slope spring	Spring occurring on the lower slope of an alluvial cone at the point where the water table slope and surface gradient are equal; also known as a border spring.
catch per unit effort (CPUE)	The average (mean) number of springsnails captured (catch) calculated by the total number of springsnails captured, and divided by the number of grabs performed to capture those springsnails (unit of effort).
channel roughness	Measure of how course the bed of a river or stream is; a measure of the amount of frictional resistance water experiences when passing over channel features.
clastic sandstones and siltstones spring	Spring originating in one of these rock types. Sandstone is a rock composed of sand-sized grains of various minerals, mostly of uniform size. Siltstone is a fine-grained sedimentary rock which mainly consists of consolidated silt.
climate change	Change in the mean or variability of one or more measures of climate (e.g., temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both.
cold springs	Springs with temperatures below 70 °F (21.1 °C).
common	Catch per unit effort between 6 and 20 individuals
confined aquifer	Aquifer that contains water that rises above the top of the aquifer in a penetrating well; also known as an artesian aquifer.
detritus	Dead particulate organic material of plants and animals
exposure	Extent to which a target resource and threat actually overlap in space or time.
fluvial deposit spring	Spring originating from fluvial deposits, which are areas of water deposited on the landscape from a flowing river/stream in the past.
grab	One sweep with a hand dip net through spring substrate
helocrene	A wet meadow spring system, with flow emerging from low gradient wetlands; often with indistinct or multiple seeping sources into a marsh.
immediacy	Action time frame of a threat; i.e., a threat can be present and acting on a species now, anticipated in the future, or historical with residual impacts
intensity	Strength of the threat itself
invasive species	Species that is nonnative to an ecosystem and causes, or is likely to cause, economic or environmental harm, or harm to human health.
limnocrene	Natural spring where water is initially forms within a basin, or large, deep pool.

local aquifer	Aquifer fed by precipitation from a large area with supported springs located between valley floors and mountain bases.
macroinvertebrate	Organism without backbones that is visible to the eye without the aid of a microscope. Aquatic macroinvertebrates live on, under, and around rocks and sediment on the bottoms of lakes, rivers, and streams.
macrophyte	Aquatic plant that is large enough to be visible to the naked eye. May be an emergent, submergent, or floating type of aquatic plant.
mountain block aquifer	Aquifer that is usually perched, relatively small, and fed by precipitation from a small area.
nonnative	Originating in a different geographic region and acclimated to a new environment.
parthenogenesis	Type of asexual reproduction in which the offspring develops from unfertilized eggs.
perched aquifer	Aquifer that occurs above the regional water table and is generally a relatively small body of water.
population	Group of individuals of the same species that have the potential to interbreed.
redundancy	Ability of a species to withstand catastrophic events.
regional aquifers	Large aquifer characterized by water that is warmer and moves slower through the aquifer, in comparison to perched and local aquifers; supported springs are supplied from recharge extending over vast areas.
relative abundance	A quantitative index of population size based on the number of individuals observed in a sample relative to other samples, which is also used to examine changes in the number of individuals in a sample to position in the springbrook from source to terminus, and to quantify habitat use.
response	Extent to which a target resource responds to specific threat
representation	Ability of a species to adapt to changing environmental conditions.
rheocrene	A spring that flows directly into a channel to form a springbrook
springbrook	Water outflow from a spring source.
spring province	Cluster of geographically nearby springs and springsbrooks
thermal spring	Springs with temperatures above 70 °F (21.1 °C).

1.0 INTRODUCTION

The Species Status Assessment (SSA) framework (Service 2016, entire) is an in-depth review of a species' biology and risks, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The SSA report is intended to support all functions of the Endangered Species Program, including the development of listing rules, recovery plans, and 5-year reviews, should the species warrant listing as an endangered or threatened species under the Act. The SSA report is a living document and we may update it periodically as new information becomes available.

On February 17, 2009, we were petitioned by the Center for Biological Diversity to list 42 Great Basin and Mojave Desert springsnails as threatened or endangered species, as appropriate, under the ESA (CBD et al. 2009). Ten of those springsnail species are presented in this SSA report while the remainder are addressed in other analyses/documents. We published a 90-day finding in the *Federal Register* on September 13, 2011 (76 FR 56608) in which we determined that the petition presented substantial scientific or commercial information for 32 of the springsnail species, including these 9 species.

This SSA report is intended to provide the biological support for determining whether or not to propose to list the species as endangered or threatened species and if so, whether or not to propose designating critical habitat. The process and this SSA report do not represent a decision by the Service whether or not to list the species under the Act. Instead, this SSA report provides a review of the best scientific and commercial information available strictly related to the biological status of the nine springsnail species. We will make a listing decision after reviewing this document and all relevant laws, regulations, and policies, and will announce the decision in the *Federal Register* at a later date. The nine springsnail species presented in this SSA report are:

- Amargosa tryonia (*Tryonia variegata*)
- Ash Meadows pebblesnail (*Pyrgulopsis erythropoma*)
- Crystal springsnail (*Pyrgulopsis crystalis*)
- distal-gland springsnail (*Pyrgulopsis nanus*)
- Fairbanks springsnail (*Pyrgulopsis fairbankensis*)
- median-gland springsnail (*Pyrgulopsis pisteri*)
- minute tryonia (*Tryonia ericae*)
- Point of Rocks tryonia (*Tryonia elata*)
- sportinggoods tryonia (*Tryonia angulata*)

The format for this SSA report includes:

- Description of the analysis framework and methodology (Chapter 2).
- Background information on the range and distribution of the nine springsnail species; general biological information for springsnails; and general information on spring characteristics, function, and hydrology important for understanding the physical and biological needs of individuals and populations (Chapter 3).

- Descriptions of the resources needed by the species at the individual, population, and species levels (Chapter 3).
- Descriptions of potential factors that may impact springsnail species' needs and current conditions (Chapter 4).
- Evaluation of the current condition of each springsnail species, including quantity and quality of springsnail habitat that is present at a spring or spring province, information on needs that may be unique to a particular species, the historical and current distribution of the species, the relative abundance (Chapter 2, herein; Sada and Mihevc 2011, p. 12) of each springsnail population, and the current conditions of each species' population(s) (Chapter 5).
- An evaluation of the probable future condition of each springsnail species, including a description of the species' viability in terms of resiliency, redundancy, and representation based on three potential future condition scenarios (Chapter 6).

1.1 State Listing Status

In reference to the nine springsnails considered herein, the state of Nevada does not include any invertebrate taxa under their state list of protected species. There are no legal protections provided under Nevada Revised Statute (NRS) 501, and they are not listed in the Nevada Administrative Code (NAC) Chapter 503. They are however, each identified as Species of Concern in Nevada. The state's Department of Conservation and Natural Resources maintains the Nevada Division of Natural Heritage (NDNH), which does track the species status of invertebrates. The NDNH recognizes all nine species considered here as critically imperiled, rank *S1* (*Tryonia angulata, T. elata, T. ericae, Pyrgulopsis erythropoma, P. crystalis, P. nanus, P. fairbankensis, P. pisteri*) or imperiled, rank *S2* (*T. variegata*). Ranks of *S2* or *S1* are defined as species with high or very high (respectively) risks of extirpation in the jurisdiction due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors. One species considered here is known to historically occur in California: the regional endemic Amargosa tryonia (*Tryonia variegata*). This species is not protected on the State of California's list of protected invertebrates.

2.0 ANALYSIS FRAMEWORK

2.1 Analysis Area

The nine springsnail species evaluated in this SSA report are distributed throughout springs and spring provinces in southern Nevada and California (Fig. 2.1). All nine species occur in the lower Amargosa Valley, on the Ash Meadows NWR (Nye County, Nevada), or immediately nearby on private land. One of these species also occurred approximately 40 km (25 mi) south of the Refuge within the same drainage (Amargosa River, Inyo County, California). These springsnail species are typically restricted in their distribution, occupying a limited number of springs and spring provinces. Species-specific location and hydrographic information is presented in Fig. 2.1 and Chapter 4.1.

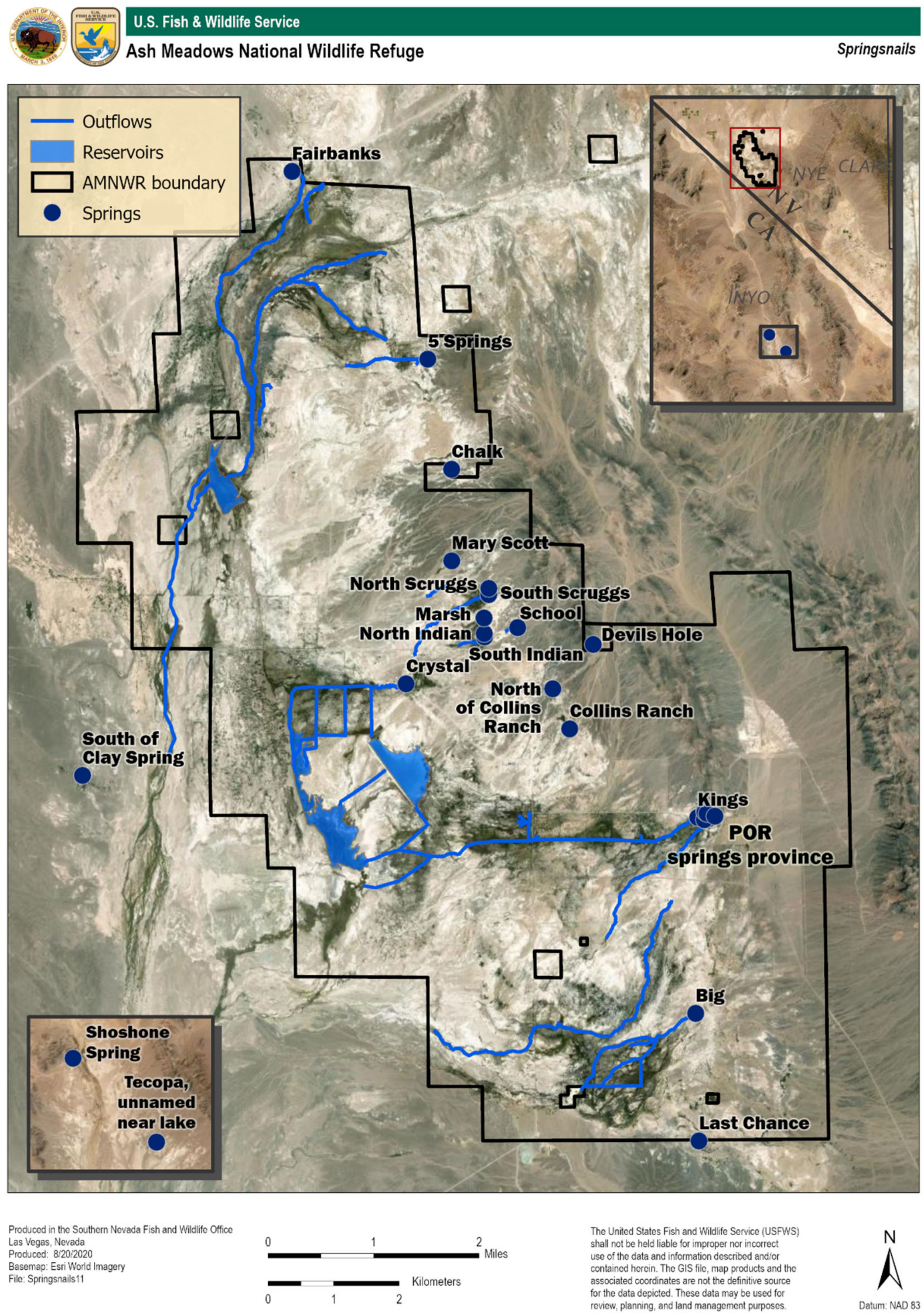


Figure 2.1. Selected springs of Ash Meadows NWR and lower Amargosa Valley. Labelled springs historically or presently support the nine springsnail species in this report.

2.2 SSA Framework

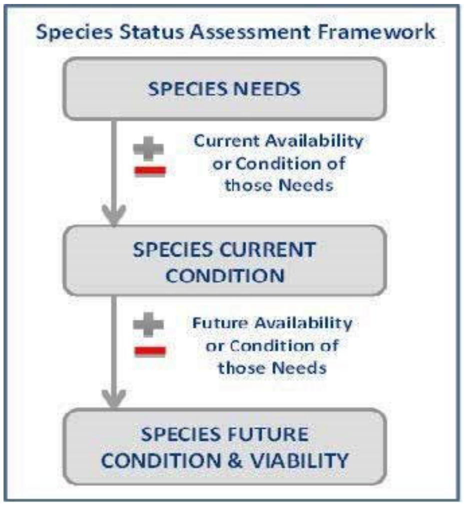


Figure 0.2. Species status assessment framework.

To evaluate the biological status of the springsnails both currently and into the future, we assessed a range of conditions to allow us to consider the species' needs and ultimately their resiliency, redundancy, and representation (3Rs). This SSA report provides a thorough assessment of springsnail biology and natural history, and assesses demographic risks, threats, and limiting factors in the context of determining the viability and risks of extinction for each species.

Definitions of the 3Rs
The following are working definitions of the 3Rs that are used throughout this document. They are derived from the SSA framework (Fig. 2.2; Service 2016, entire) and supporting material (Service 2020, entire):

- **Resiliency** is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature, rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford et al. 2011, p. 40). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions. We can best gauge resiliency by evaluating population level characteristics such as: demography (abundance and the components of population growth rate -- survival, reproduction, and migration), genetic health (effective population size and heterozygosity), connectivity (gene flow and population rescue), and habitat quantity, quality, configuration, and heterogeneity. Also, for species prone to spatial synchrony (regionally correlated fluctuations among populations), distance between populations and degree of spatial heterogeneity (diversity of habitat types or microclimates) are also important considerations.

- **Redundancy** is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population heath and for which adaptation is unlikely (Mangal and Tier 1993, p. 1,083). We can best gauge redundancy by analyzing the number and distribution of populations relative to the scale of anticipated species-relevant catastrophic events. The analysis entails assessing the cumulative risk of catastrophes occurring over time. Redundancy can be analyzed at a population or regional scale, or for narrow-ranged species, at the species level.

- **Representation** is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments-- referred to as adaptive capacity--is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra et al. 2015, p. 1,269). Species adapt to novel changes in their environment by either (1) moving to new, suitable environments; or (2) by altering their physical or behavioral traits (phenotypes) to match the new environmental conditions through either plasticity or genetic change (Beever et al. 2016, p. 132; Nicotra et al. 2015, p. 1,270). The latter (evolution) occurs via the evolutionary processes of natural selection, gene flow, mutations, and genetic drift (Crandall et al. 2000, pp. 290–291; Sgro et al. 2011, p. 327; Zackay 2007, p. 1). We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In assessing the breadth of variation, it is important to consider both larger-scale variation (such as morphological, behavioral, or life history differences which might exist across the range and environmental or ecological variation across the range), and smaller-scale variation (which might include measures of interpopulation genetic diversity). In assessing the dispersal ability, it is important to evaluate the ability and likelihood of the species to track suitable habitat and climate over time. Lastly, to evaluate the evolutionary processes that contribute to and maintain adaptive capacity, it is important to assess: (1) natural levels and patterns of gene flow, (2) degree of ecological diversity occupied, and (3) effective population size. In our species status assessments, we assess (or estimate via proxy) all three facets to the best of our ability based on available data.

2.3 Methodology

In preparing this SSA report, we reviewed available reports and peer-reviewed literature, unpublished surveys, consulted with species experts, planned site visits, and reviewed aerial imagery and Geographic Information Systems (GIS) data. We considered uncertainties in our assessment of the species' life history, current conditions, and future conditions. We also reviewed the relevant literature for similar and co-occurring species.

The general approach involved a conceptual model to identify the species needs of springsnails, and the subsequent evaluation of springsnail threats and abundance estimates at each location. The basic species needs included adequate spring discharge (amount), free-flowing water (without impoundment), water quality, and suitable substrate and vegetation. A detailed description of how the species needs above relate to springsnail biology is presented later in Chapter 3.

With respect to threats, we used data collected previously, and data collected specifically for this report to evaluate individual springsnail populations. Here, we primarily relied on historical data from Hershler and Sada (1987, entire), and more recent information from three data sets (USGS 2020, unpubl.; Sada 2020, unpubl.; Service 2020, unpubl.) to assess the effects of current threats on populations and their habitat, and their response to those threats. The Sada (2020) data set referenced here included was acquired directly from the principal investigator's "springs database" for Ash Meadows, a compilation of data since Sada first visited the Ash Meadows springs for their published description in 1987 (Hershler and Sada, 1987, entire). The USGS 2018 and Service 2020 surveys were conducted specifically for this report, as to provide the most recent status of these populations. The USGS 2018 surveys are in preparation for publication under a USGS data release.

Threats were categorized to inform upon the specific nature of the each threat. These characterizations were modified from those described in Sada (2017, pp. 23–25), and used previously for springsnail evaluation. These included information on the timing, strength, amount of habitat involved, and the response of springsnail populations to various threats. The four threat characterizations and their qualitative categories within them include:

- *Immediacy* (timing of threat): unknown (0), historical (1), current (2), imminent (3), and future (4);
- *Intensity* (strength of the threat): unknown (0), negligible (1), low (2), moderate (3), or high (4);
- *Exposure* (amount of area exposed to a threat): unknown (0), insignificant (1), small (2), moderate (3), high (4), very high (5), and all available habitat (6);
- *Response* (of population to the threat): unknown (0), expanded (1), contracted (2), displaced (3), basic needs inhibited (4), or mortality (5).

Also important for evaluation of springsnails are species occurrence data and the estimation of abundance. Survey data were compiled from multiple years of surveys and multiple surveyors. Methodologies to assess and describe abundance varied slightly between datasets. To address these variations, we used standardized relative abundance categories for each springsnail population based on catch per unit effort (CPUE). The number of springsnails in each category is consistent with those from historical surveys. CPUE is the average (mean) number of springsnails captured (catch), calculated by dividing the total number of springsnails captured by the number of grabs (unit of effort). For example, if 150 springsnails were captured in 10 grabs, the catch per unit effort would be 15. This assessment was used to determine abundance (scale below), and the extent of occupied habitat. The number of springsnails in each category follows those of Sada (2017, p. 30). The relative abundance categories are:

- *None* = catch per unit effort of 0 individuals;
- *Scarce* = average catch per unit effort less than 6 individuals;
- *Common* = average catch per unit effort between 6 and 20 individuals;
- *Abundant* = average catch per unit effort greater than 20 individuals.

Based on all the available information at each spring or spring province (e.g., species needs, threats, springsnail abundance, and other information), each habitat was categorized indicative of its condition to support springsnails. Habitat condition is classified into four levels relative to springsnails using expertise of Service staff, and other qualified resource professionals:

- *High* = spring ecosystem functioning near optimum; little room for improvement;
- *Moderate* = spring ecosystem functioning somewhat well; some room for improvement;
- *Low* = spring ecosystem functioning less than optimal; significant room for improvement;
- *Dry* = no surface water.

For most species, our recent survey data were collected from 2018–2020; however, some springs where species had previously been documented were not accessible, and others could not be located. In some cases the characterizations above were difficult to apply, and categorized as unknown (see Appendix B). Where more than one species of springsnail occurred at a site, the surveyor identified springsnails to genus using magnification in the field, and determined at minimum that two genera co-occur. Thus, abundance estimates were indicative of genera. All spring habitats and constituent species are well documented at Ash Meadows (Hershler and Sada 1987, entire); relatively few springs discussed here were problematic in this regard, given the site-specific nature of springsnails and the species specifically considered in this report (see spring descriptions in Chapter 5 and Appendix B). It is important to recognize that springsnail population size varies temporally and spatially (see Chapter 3.1.2). We also recognize that random sampling and seasonal variation affect survey results at springs where only a few measurements are made or other variation exists, such as slight deviations in equipment or investigator technique. Finally, in some instances we excluded extreme outlier values as anomalies or errors, recognizing that further evaluations could provide insight or explain inconsistencies.

In addition to considering both threats and abundance, we also considered information on any beneficial effects associated with past or ongoing conservation measures. This aspect is of particular importance for these nine species, as all but one (Amargosa tryonia) occur within the boundaries of the Ash Meadows NWR. The Refuge affords protection from new and further direct human-caused impacts, and actively restores habitat when possible. The Refuge seeks to repair habitat for species in accordance with the 2009 Comprehensive Conservation Plan (CCP) for the Desert NWR Complex, and the Ash Meadows Natural Resource Management Plan (in review fall 2020). In many cases, historical negative effects occurred, such as water diversions or dredging, that no longer cause substantial impacts to springsnails due to site restoration. In other cases partial restoration and/or significant time has occurred such that no further damage can occur, and the site condition is considered stable or naturalized. However, not all threats can be removed or partially mitigated due to financial or logistical challenges.

As obligate aquatic taxa in an extreme desert environment, the availability of water at a site is among the foremost species needs for all springsnails evaluated in this report. The four species needs are directly or indirectly influenced by springflow (adequate water supply, free-flowing water, vegetation and substrate, and water quality). Therefore, in the consideration of resiliency, both for population and ultimately the viability of species, the value of “adequate water supply” ranked highest. Accordingly, reduction in springflow is the most significant threat for springsnails. We also considered the perennial yield data for the hydrographic area to determine how much groundwater is currently used and how any potential or future reductions in water supply might affect individual populations and species.

Finally, using all the habitat information above under the 3R framework (resiliency, redundancy, and representation), and the distribution of each species across the habitats, we estimated species-level viability. Viability scores were categorized as one of five sequential levels ranging from highest to lowest. Rankings are qualitative assessments of species viability based on the knowledge and expertise of Service staff, and other technical experts and resource professionals. Viability categories are defined as follows:

- *Very High* = species condition at optimum for resources available;
- *High* = species condition is secure; but little room for improvement among 3Rs;
- *Moderate* = species condition at marginal levels; sustaining but room for improvement;
- *Low* = species condition at marginal level; significant room for improvement among 3Rs;
- *Very Low*= species condition near extirpation or extinction.

To evaluate possible future condition of these nine species, we selected three reasonable future condition scenarios based on the most significant threat—a reduction in springflow or discharge. Here, we define springflow or discharge as water flowing across the land surface. Reduced springflow is dependent on many factors, but for springs sourced from regional aquifers as is the case with Ash Meadows, groundwater pumping for human development and changes in precipitation and temperature from climate change likely influence spring discharge. This theme is directly reflected in the three potential future scenarios of Chapter 6.2. The order of these scenarios do not reflect the likelihood of occurrence. Alternatively, the following three scenarios are not inclusive of all possible scenarios, but chosen to represent a range of possible outcomes from the current condition to those of extreme reductions in springflow, each with increasing risk to species viability. These scenarios represent: (1) no measureable reduction in springflow from current conditions (*Scenario 1*), (2) a reduction of springflow and discharge beyond natural fluctuations but not to an extreme extent (*Scenario 2*), and (3) an extreme reduction or elimination of springflow (*Scenario 3*). Because *Scenario 1* is similar to current conditions, some information pertinent to this scenario occurs in Chapter 5, "Current Conditions–Springs Habitats and Species Viability"; additional species-specific information for *Scenario 1* is under "Potential Future Conditions – Species Viability" (Chapter 6). For *Scenario 3*, we determined spring conditions would likely result in springsnail extirpation or extinction, and this outcome is described in Chapter 6. The overall summary table of species viability across all species and their habitats is presented in Chapter 7.

For the purpose of this assessment, we generally defined viability as the ability of a species to sustain populations in natural spring ecosystems over time. We chose 50 years for the timeframe of our future condition analysis because it is within the range of available hydrological and climate change model forecasts (see Intergovernmental Panel on Climate Change (IPCC) 2014, pp. 10–15; and Groundwater Characterization and Effects in Death Valley Regional Groundwater Flow System, Nevada and California, USGS 2020, entire). Additionally, because of the short generation time of these springsnails (approximately 1 year), 50 years encompassed approximately 30 to 40 generations, which is a relatively high number of generations over which to observe effects to the species.

3.0 Species Ecology and Resource Needs

This chapter presents general information on the historical range and distribution of the nine springsnail species, followed by basic biological information on taxonomy and genetics, morphological features, life history traits, and feeding habits. Spring characteristics and function are also described because springs and spring provinces constitute springsnail habitat, and the physical and biological needs of the springsnail species. Additional species- and area-specific descriptions and information are in Chapter 5.

3.1 Springsnail Biogeography, Biology, and Habitat

3.1.1 Range and Distribution

There are more than 134 recognized species of *Pyrgulopsis* (Hershler et al. 2013, p. 28), and *Pyrgulopsis* is the largest genus of aquatic mollusks in North America (Hershler and Sada 2002, p. 255; Liu and Hershler 2005, p. 284). The genus *Tryonia* contains over 20 species that range throughout the southern U.S. (Hershler 2001, p. 1; Hershler et al. 1999, p. 378), with most concentrated in the southwest (Hershler 2001, p. 1). Most springsnail species are endemic to a limited number of springs within a valley or hydrographic basin (Hershler and Sada 2002, p. 255). The current range and distribution of springsnails likely reflect late Cenozoic hydrographic history. Springsnails have likely been transported by other means, such as human activities (Hershler et al. 2005, p. 1,763; Hershler and Liu 2008, p. 99; Hershler and Sada 2002, p. 255). Elevations of the springs and spring provinces where these species occur in Nevada and California are typically below 2,200 m (7,218 ft) (Sada 2009, p. 3). Spring ownership for the nine species considered here include Federal and private lands.

3.1.2 Biology and Life History

3.1.2.1 Taxonomy

Each of the nine springsnail species we review in this SSA (Table 3.1) are recognized and accepted as unique species (Hershler and Sada 1987, entire; Hershler 1998, entire; Hershler et al. 2013, entire). Of the nine springsnail species, six reside within the family Hydrobiidae, and genus *Pyrgulopsis* (Call and Pilsbry 1886, entire), and four within the family Cochliopidae and genus *Tryonia* (Stimpson 1865, entire). The scientific names for these species represent the most current taxonomic classifications; however, the classification of gastropods in general has changed during the past 2 decades (Brown and Lydeard 2010, p. 294) and is still evolving for springsnails (Hershler and Liu 2017, p. 58; Johnson et al. 2013, p. 251). For example in Hershler et al. (2013, entire), authors revised populations of two Ash Meadows area pyrgs (Sanchez pyrg (*P. sanchezi*) and curved filament pyrg (*P. licina*), although these two species are not addressed in this analysis.

The nine species of springsnails summarized in this report occur solely in the Amargosa Valley on the Ash Meadows NWR (and immediately adjacent on private land), and two springs in nearby towns of Shoshone and Tecopa, California. These nine species were formally described based on morphological differences in the both the shell and soft tissue anatomy (Hershler and Sada 1987, entire). All of these springsnails are small, and measure approximately 2–4 millimeters (mm) [0.08–0.16 inches (in)] in shell length. Beyond the most basic genus-level differences in shell morphology explained in the following section, springsnails often appear similar to nonexperts and experts alike. Species identification requires technical expertise and laboratory equipment. For the endemic Amargosa Valley springsnails surveyed for this report [Amargosa tryonia (*Tryonia variegata*), Ash Meadows pebblesnail (*Pyrgulopsis erythropoma*), Crystal springsnail (*Pyrgulopsis crystalis*), distal-gland springsnail (*Pyrgulopsis nanus*), Fairbanks springsnail (*Pyrgulopsis fairbankensis*), median-gland springsnail (*Pyrgulopsis pisteri*), minute tryonia (*Tryonia ericae*), Point of Rocks tryonia (*Tryonia elata*), and sportinggoods tryonia (*Tryonia angulata*)], species identification in this report was assumed by identification during field surveys to genus, combined with the original descriptions provided in Hershler and Sada (1987, entire).

Table 3.1. Hierarchy of main taxonomic ranks, scientific name and author, and common names of the ranks reviewed in this SSA report.

Taxonomic Rank	Scientific Name and Author	Common Name(s)
Kingdom	Animalia	animal
Phylum	Mollusca (Linnaeus 1758)	mollusk
Class	Gastropoda (Cuvier 1795)	gastropod, snail
Order	Neotaenioglossa (Haller 1892)	
Family	Hydrobiidae (Troschel 1857)	mud snail, pebblesnail, springsnail
Genus	*Pyrgulopsis* (Call and Pilsbry 1886)	pyrg
Species	*Pyrgulopsis erythropoma* (Pilsbry 1899)	Ash Meadows springsnail
	Pyrgulopsis crystalis (Hershler and Sada 1987)	Crystal springsnail
	Pyrgulopsis nanus (Hershler and Sada 1987)	distal-gland springsnail
	Pyrgulopsis fairbankensis (Hershler and Sada 1987)	Fairbanks springsnail
	Pyrgulopsis pisteri (Hershler and Sada 1987)	median-gland springsnail
Family	Cochliopidae (Tryon 1866)	mudsnail, springsnail
Genus	*Tryonia* (Stimpson 1865)	tryonia
Species	*Tryonia variegata* (Hershler 1998)	Amargosa tryonia
	Tryonia ericae (Hershler and Sada 1987)	minute tryonia
	Tryonia elata (Hershler and Sada 1987)	Point of Rocks tryonia
	Tryonia angulata (Hershler and Sada 1987)	sportinggoods tryonia

With respect to these springsnails, morphology (and in few cases neutral genetic markers) has been used for taxonomic descriptions, but the functional genetic diversity of springsnails is not well understood, particularly as it relates to their ability to adapt to short- and long-term environmental changes. Based on their often restricted distributions within a spring or springbrook, they appear to be limited to a range of physical and biological parameters that exist within that occupied area (Sada 2017, p. 13), one known parameter being their dependency on perennial water (Hershler and Liu 2008, p. 92). In addition, long-term isolation and small population size within some spring systems potentially make springsnails weakly adapted to survive novel threats such as predation and competition (Sada 2017, p. 11). In a small number of exceptions shown in this report, particularly the largest spring habitats, springsnails of one species remains common, while another may not, in the presence of introduced organisms. However, threats to spring discharge or habitat structure often constitute threats to the springsnail population in general.

3.1.2.2 Morphological Description

Species within the genera *Pyrgulopsis* and *Tryonia* appear relatively similar to inexperienced and unaided eyes, but have been described and differentiated based on subtle morphological characteristics employed by Hershler and Sada (1987, pp. 780–785) and Hershler (1989, pp. 176–179; 1994, pp. 2–4; 1998, pp. 3–11; 2001, p. 2), among others. Species descriptions have been published by examining adults, sometimes as living specimens, but primarily from dry and alcohol-preserved specimens using scanning electron micrographs (Hershler and Sada 1987, pp. 780–785; Hershler 1989, pp. 176–179; 1994, pp. 2–4; 1998, pp. 3–11; 2001, p. 2). Closely related springsnail species often are distinguishable based on characteristics of their internal anatomy (Burch 1982, p. 7; 1989, p. 37). Species within both genera are differentiated by thorough detailed examination and comparison of differences among morphological characteristics of adult shell, operculum (a secreted plate that closes the aperture), the digestive system (including tooth-like radulae), body pigmentation, pallial cavity (the space that contains respiratory organs), and reproductive system (Hershler and Sada 1987, pp. 780–785; Hershler 1989, p. 176–179; 1994, pp. 2–4; 1998, pp. 3–11; 2001, p. 2).

Figure 3.1. Shell of *Pyrgulopsis* (Muddy River, Clark County, Nevada)

In general, species of *Pyrgulopsis* and *Tryonia* are similarly sized. Freshly hatched *Pyrgulopsis* less than a week old may be less than 0.3 mm up to 0.8 mm (0.01 in up to 0.03 in) in total length (Mladenka and Minshall 2001, p. 208; Wells et al. 2012, pp. 74–75; Pearson et al. 2014, p. 66). The shell heights of adult *Pyrgulopsis* may range between approximately 1 and 5 mm (0.04 and 0.2 in) and have three to five whorls (Hershler 1998, pp. 4–9), whereas adult grated tryonia shell height may be approximately 3 to 7 mm (0.1 to 0.3 in) and have five to nine whorls (Hershler 2001, p.7).

In general, species of *Pyrgulopsis* and *Tryonia* are morphologically similar with hardened shells and soft anatomy. Both have spiraling conic shells (one spiral is a whorl) with a shell opening (aperture) that can be sealed with an operculum when the soft anatomy is withdrawn into the shell (Burch 1982, pp. 64–65; 1989, p. 35). The soft anatomy includes a foot, head, and a mantle that covers the visceral mass, which contains most of the organs (Brown and Lydeard 2010, p. 279; Pyron and Brown 2015, p. 386). The mantle extends over the head and has a mantle cavity where gills are protected by the shell (Burch 1989, p. 53; Brown and Lydeard 2010, p. 279; Pyron and Brown 2015, p. 386). When relaxed, the head and flat-bottomed foot can extend from the shell opening (Pyron and Brown 2015, p. 386). The foot is used for locomotion as mucous is secreted over a substrate (Pennak 1953, pp. 667–671; Brown and Lydeard 2010, p. 279).

Shell appearance changes as springsnails mature. Young springsnails have near translucent shells that progressively develop coloration and whorls as they near adult size (Mladenka and Minshall 2001, p. 208; Wells et al. 2012, pp. 73–74; Pearson et al. 2014, p. 66). Adult shells often appear (with a skin-like layer covering the shell) to be tan or brown in color for *Pyrgulopsis* (Hershler 1998, pp. 15–108) and gray or clear for *Tryonia* (Hershler 2001, p. 3).

3.1.2.3 Reproduction, Survival, Growth, and Longevity

Limited information is available specific to the life history of the nine springsnail species; most of the information used is inferred or generalized from closely related taxa. Less information is available on the life history of *Tryonia* relative to *Pyrgulopsis*. However, in general, data are available on springsnail species' size, and the timing and duration of life stages vary depending on environmental conditions.

Springsnails are dioecious (Hershler 1998, p. 10; 2001, pp. 3–5), where male and female organs occur in separate individuals, and are sexually dimorphic (animals with different male and female forms) in size. Females tend to be larger than males among both *Pyrgulopsis* (Hershler and Landye 1988, pp. 8–41, 60; Mladenka and Minshall 2001, p. 209) and *Tryonia* (Hershler and Thompson 1987, p. 27; Hershler 2001, pp. 6–14). For example in the related grated tryonia (*T. clathrata*), males are often half the height of females (Hershler and Thompson 1987, p. 27; Hershler 2001, pp. 6–14) as compared to 80–90 percent or more for *Pyrgulopsis* species (Hershler and Landye 1988, p. 60).

After internal fertilization, a springsnail's life cycle (Fig. 3.2) begins as an egg (Kabat and Hershler 1993, p. 6). In *Pyrgulopsis* species, a female lays an egg capsule containing multiple embryos[2] (oviparous) on a firm substratum (Hershler 1998, p. 14). There is little specific information about species' substrate needs, but among related species, egg capsules mature on the substrate and hatch after a brief time, approximately 8–10 days (Brown et al. 2008, p. 487). The number of eggs produced by an individual female *Pyrgulopsis* is unknown. In contrast, *Tryonia* are ovoviviparous (Hershler 2001, p. 3) with eggs being held in a brood pouch (Brown and Lydeard 2010, p. 282) in which they develop until they hatch internally (Dillon, Jr. 2006, p. 251).

[2] Pearson et al. (2014, p. 66) report that "an egg containing a single snail rather than an egg capsule containing multiple embryos" was deposited by Page springsnails (*Pyrgulopsis morrisoni*).

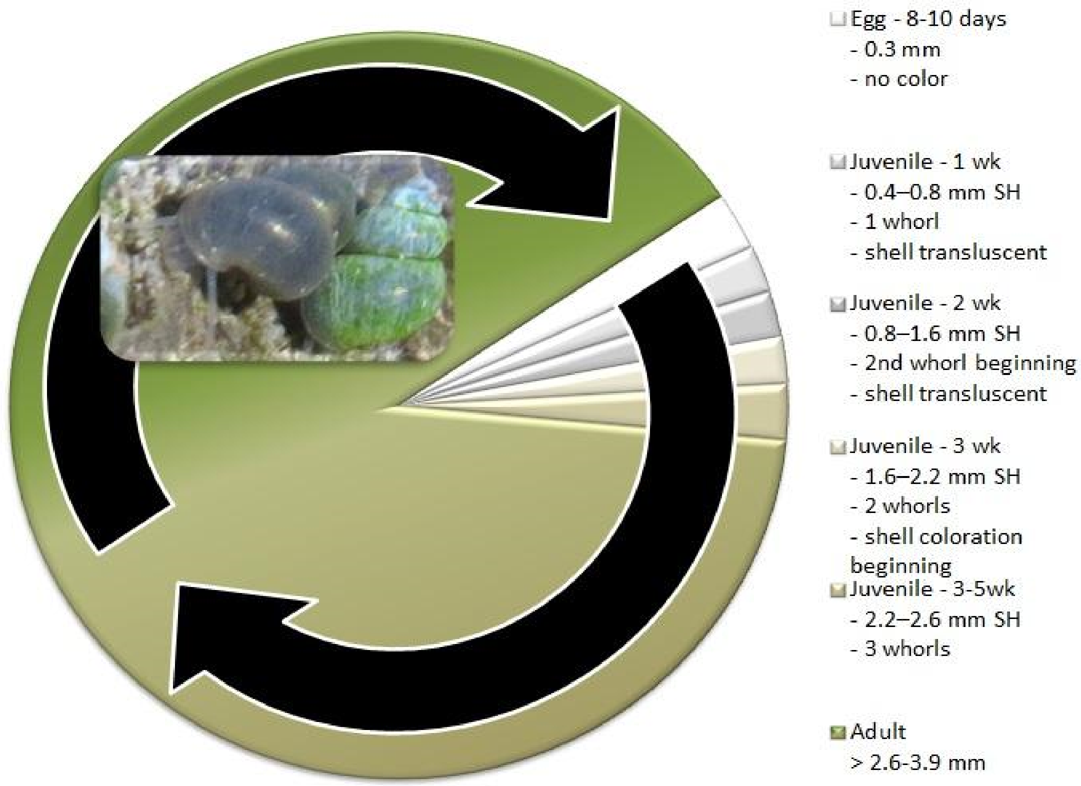


Figure 3.2. Basic life cycle of a springsnail. Graphic adapted from Pearson et al. 2014, Table 1 for *Pyrgulopsis morrisoni*. (SH = shell height). The representative photo (inset) pictured above is *Pyrgulopsis turbatrix* (C. Kallstrom/Service).

Springsnails mature from eggs to adulthood relatively quickly. In captivity under constant conditions in the related Page springsnail (*Pyrgulopsis morrisoni*), eggs hatch approximately 1 week after being laid (Pearson et al. 2014, p. 66). *Pyrgulopsis* species develop from freshly hatched eggs to adult size in 6 or 7 weeks (Wells et al. 2012, p. 73; Pearson et al. 2014, pp. 66–67); however, it is unknown at what age they become sexually mature. *Pyrgulopsis* species are described to have limited ability or tendency to move (vagility) (Liu et al. 2003, p. 2,771; Hershler and Liu 2008, p. 100). Therefore, once eggs have been deposited, they hatch into young springsnails and likely remain near the area of hatching through adulthood unless they are dispersed by stream current.

The annual temperature regime of springs influences the occurrence and abundance of springsnails and subsequent population dynamics. Among *Pyrgulopsis* occupying warm springs, hatching and recruitment may occur continuously throughout the year (Mladenka and Minshall 2001, p. 209) and are dependent on water temperature. In thermal springs (see Glossary), hatching typically increases between winter and spring when water temperatures are near their thermal minimum (Mladenka and Minshall 2001, p. 209). In cold springs (see Glossary), hatching typically increases between summer and fall when spring water temperatures are near their thermal maximum (Lysne et al. 2007, pp. 649–650). Thus, the relative abundance of springsnails within a spring varies among species, and can fluctuate dramatically during the year (Mladenka and Minshall 2001, Fig. 2; Martinez 2009; p. 31). Population relative abundance or density predominantly reflect numbers of adult and larger juveniles, because they are more readily detected (observed or captured) during monitoring. Within a single year, the density of springsnails per square meter (~11 ft^2) could fluctuate between 10s and 10,000s (Mladenka and Minshall 2001, p. 208). Springsnails high rates of fecundity and recruitment may contribute to population resiliency (Martinez and Sorensen 2007, p. 31).

The annual fluctuation in densities observed in some studies (e.g., Mladenka and Minshall 2001, p. 207; Martinez 2009, p. 31) is additionally influenced by the lifespan of springsnails. The average lifespan for most species of springsnails is thought to be 9 to 15 months (Pennak 1953, p. 680). Laboratory studies of two species of *Pyrgulopsis* have documented similar lifespans. One study of the Page springsnail documented a high rate of survival to 10 months (Wells et al. 2012, pp. 74–75). Another study of the Jackson Lake springsnail (*P. robusta*) documented lifespans of individuals between 11 and 14 months with an average survival of approximately 13 months (382 days) (Lysne et al. 2007, p. 649). At this time, the best available information suggests the probable lifespan of *Tryonia* may be similar to *Pyrgulopsis* (i.e., a range of 9–15 months), given the similarity in other life history traits; however, this is currently unknown.

3.1.2.4 Feeding Habits

Pyrgulopsis and *Tryonia* species are herbivores or detritivores that primarily graze on the periphyton or biofilm) on exposed surfaces of macrophytes (see Glossary) and substrate (Mladenka 1992, pp. 46, 81; Hershler and Sada 2002, p. 256; Martinez and Thome 2006, p. 8; Pyron and Brown 2015, p. 401). Macrophytes include native species such as rushes (*Juncus* spp.), sedges (*Carex* spp.), or spikerushes (*Eleocharis* spp.); or nonnative species including watercress (*Nasturtium* spp.). Periphyton biofilm consists of algae, bacteria, detritus, fungi, diatoms, and protozoa contained within a matrix of polysaccharides (Lysne et al. 2007, p. 649; Vu et al. 2009, p. 2,536). While periphyton may be more easily ingested and more nutritious than macrophytes, macrophytes can be consumed if periphyton supplies are depleted (Pyron and Brown 2015, p. 399). If this occurs at high snail densities, macrophyte richness may decrease (Sheldon 1987, p. 1,928). The common occurrence of springsnails among the periphyton-poor roots of non-native watercress remains unexplained.

3.2 Spring Characteristics and Function

Desert springs support relatively small aquatic and riparian systems as surface flow and are maintained by groundwater. They range widely in size, water chemistry, morphology, landscape setting, and persistence. They occur from mountain tops to valley floors, some of which occur in clusters (defined in this SSA report as spring provinces), and are predominantly isolated from other aquatic and riparian systems. Springs occur where groundwater reaches the earth's surface, often through fault zones or rock cracks (Springer and Stevens 2009). Springs are highly individualistic ecosystems, each differing due to variation in aquifer geology, morphology, discharge rates, regional precipitation, biogeographic history, and anthropogenic impacts (Stevens et al. 2020).

Nearly all springs discharge is derived from infiltration of surface water, and springs hydrology depends on subterranean groundwater movement through and emergence from aquifers. Aquifer structure and function are influenced by regional and local geologic strata in relation to geologic structures (faults, fractures), which control groundwater movement and emergence. Geologically, the Nevada and California regions in this analysis are dominated by graben valleys and intervening horst mountain ranges. Most valleys contain alluvial sediments that are often permeable aquifers. These valley aquifers sometimes are recharged by springtime runoff during snowmelt from adjacent mountain ranges. There are also regional aquifers that control groundwater transport between valleys. Regional aquifer groundwaters often are ancient and are somewhat buffered from climate and annual precipitation patterns, as compared to valley aquifers. In addition, a large number of montane aquifers exist, from which many Great Basin springs emerge, many of which support springsnails.

.

Three main aquifer types occur in Nevada and the Great Basin (Sada and Mihevc 2011, pp. 1–2). These aquifers differ primarily in their water transit time or residence time, and groundwater depth, which in turn affects water temperature, water geochemistry, and spring discharge. Sada and Mihevc (2011, p. 2) describe these aquifers as follows:

- Mountain block aquifer springs have short residence times, so they are cooler and contain fewer dissolved chemical constituents than water in aquifers with longer residence time. These springs are generally small, often ephemeral, and occur in the mountains; however, some are perennial and support springsnails and other endemic fauna, such as stoneflies (Plecoptera).
- Local aquifer springs are generally warmer than mountain block aquifer springs and contain higher concentrations of dissolved chemical constituents. Also, springs fed by local aquifers are usually located on alluvial fans near the base of mountains, although they can occur in the central parts of some valleys, primarily in valleys without springs fed by regional aquifers.
- Regional aquifer springs have long residence times (generally hundreds to thousands of years), as well as high and constant discharge rates, warm temperatures, and elevated concentrations of dissolved chemical constituents. They generally occur on valley floors near the center of a valley. The springs emerging in Ash Meadows and the Amargosa River basin generally are of this type.

A spring’s size (aquatic habitat) is generally a function of discharge, which can be affected by precipitation and evapotranspiration. Also, springs can be characterized as an endpoint in a continuous spectrum of groundwater discharge processes (van der Kamp 1995, pp. 5–6), or points of focused groundwater discharge from groundwater flow systems. These flow systems transport groundwater from recharge areas to discharge areas usually under the influence of gravity. The rate of springflow averaged over several years equals the average rate of recharge to the flow systems that feed the spring (van der Kamp 1995, pp. 8). The annual rate of groundwater recharge is always less than the annual precipitation, and can be modeled on the basis of aquifer properties, e.g., precipitation and evapotranspiration. Overall, any evapotranspiration loss results in reduced flow from springs, which is the principal reason why many small springs dry up entirely during hot, dry weather (van der Kamp 1995, pp. 8).

Within a spring's flow system, environmental characteristics [for example, temperature and dissolved oxygen (DO)] vary depending on proximity to the spring's main source of water, also called the springhead. Environmental variation is typically lowest near the springhead. Variation increases downstream from the springhead with higher variability in temperature, DO concentration, and other factors (Deacon and Minckley 1974, pp. 396–397). As a result, the composition of springhead and downstream communities is usually gradational, and many species of invertebrates become absent from downstream habitats (Hayford et al. 1995, p. 83; Hershler 1998, p. 11; O'Brien and Blinn 1999, p. 225). Water temperature at many springs varies little throughout the year while other factors vary considerably. The average water temperature and the variability of temperature of the springbrook are controlled by channel geometry, solar radiation, air temperature, season, and other factors. Groundwater temperatures about 10 m (33 ft) below the surface are typically constant, where the annual fluctuation of surface temperature does not penetrate. However, relevant to springsnails, the water quality can change due to ambient influences above ground, and may limit the distribution of specific species.

Another environmental characteristic that can vary among and within springs is geochemistry, which is strongly influenced by aquifer geology (Sada and Pohlmann 2002, p. 2). Unmack and Minckley (2008, pp. 28–29) describe the role that carbon dioxide, bicarbonate, and calcium carbonate provide in springs ecological function. Confined groundwater often carries carbon dioxide from decomposing organic matter in which it passes during infiltration, and sometimes the strata through which it moves. Carbon dioxide combines with water to form weak carbonic acid, which dissolves calcium carbonate rocks to form bicarbonate. Groundwater gas concentrations vary with pressure and temperature, which are often released when a spring emerges. A result of these processes is deposition of insoluble calcium carbonate as travertine, which produces the hard substrate that armors many Great Basin springbrooks, thus reducing bank erosion and preventing water from either entering or leaving the springbrook channel (Sada and Cooper 2012, p. 18).

Riparian vegetation within and adjacent to arid springs exhibit unique characteristics due to their distinctive environments as well as colonization and extirpation dynamics that characterize these small, isolated habitats. Riparian vegetation associated with springs may be restricted to the immediate boundaries of a spring's aquatic habitat, or it may follow water that extends outward for substantial distances. Typical vegetation at large and minimally disturbed springs includes sedges, rushes, grasses (e.g., *Distichlis* sp.), and woody phreatophytes (e.g., willows (*Salix* sp.)). In Ash Meadows, mesquite (*Prosopis* spp.) is present at some springs, while vegetation at seeps is more often dominated by grasses and rushes (Sada and Pohlmann 2006, p. 7). The continually waterlogged condition of some riparian zones creates anaerobic conditions that slow decomposition of plant material, which facilitates soil development (Coles-Ritchie et al. 2014, p.

2).

Calcium and other mineral precipitates characterize riparian zone soils around Ash Meadows springs (Crews and Stevens 2009), creating inhospitable germination conditions for many riparian plant species, and bacterial conditions that oxidize organic matter, limiting soil development. Such a process reduces riparian plant and ground-dwelling invertebrate biodiversity, and fosters conditions that support endemic plant species, which include nearly a dozen species in this Great Basin valley.

Freshwater springsnails are indicators of spring inhabitants or conditions of spring ecosystems, most of which are characterized by permanent water with relatively constant discharge and flow rates. Springs that harbor springsnails may have a high mineral content but must be relatively unpolluted (Mehlhop and Vaughn 1984, p. 69). The presence of springsnails indicates that the supporting aquifer and the spring's geomorphology are relatively intact and functioning (Mehlhop and Vaughn 1994, p. 69).

3.3 Physical and Biological Needs of Springsnails

The current condition and potential future conditions of springsnail populations are most influenced by those species needs that are critical for survival and reproduction. Based on our review of the best available scientific and commercial information, and the knowledge and expertise of Service staff and other technical experts, we determined the following spring conditions are most critical in influencing the physical and biological needs of springsnails: (1) sufficient water quality, (2) adequate substrate and vegetation, (3) free-flowing water, and (4) adequate spring discharge (Fig. 3.3). When each of these physical and biological needs is satisfied and functioning within a spring, stable populations of springsnails are expected. Following are descriptions of each species need and how we categorized each to evaluate current conditions (Chapter 5) and potential future conditions (Chapter 6) of the nine springsnail species.

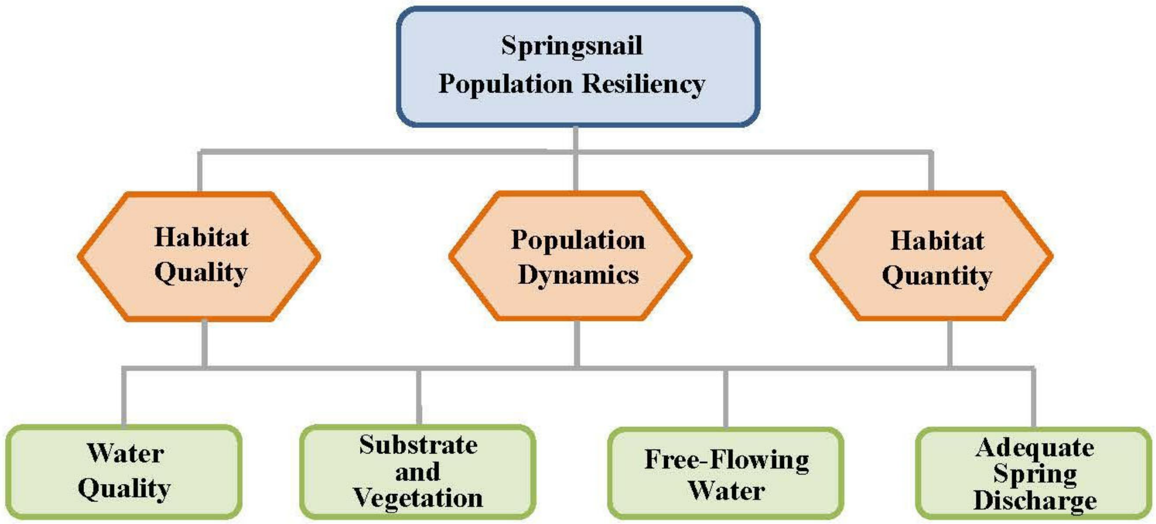


Figure 3.3. Physical and biological needs of springsnail species that influence their populations.

3.3.1 Water Quality

Pyrgulopsis and *Tryonia* species are sensitive to water quality and require specific parameters to thrive (Sada 2008, p. 59; Sada 2009, p. 3). Distribution of *Pyrgulopsis* within springs varies according to temperature, water chemistry (including carbon dioxide, DO, and conductivity), and flow regime (Hershler 1998, p. 11; Mladenka and Minshall 2001, pp. 209–211). Springsnails are typically most abundant at the spring sources and decrease in abundance farther away from the springhead. Such distribution patterns may be due to decreased water quality or increased variability in the environment (Hershler 1998, p. 11; Hershler and Sada 2002, p. 256; Martinez and Rogowski 2011, pp. 218–220). This gradient in abundance is evident in small springs (Hershler 1998, p. 11), including many that occur in Ash Meadows. Spring sources afford relatively constant water temperature, discharge, and water geochemistry conditions, while these parameters become more variable downstream (Sada 2009, p. 3).

Springs exhibit various ranges in temperatures. Springsnails have been found to reside in conditions where water temperatures (for all inhabited springs) can range from 3 degrees Celsius (°C) (37 degrees Fahrenheit (°F)) to 36 °C (97 °F) (Sada 2009, p. 3). *Pyrgulopsis* species generally occur in colder water within this range, while *Tryonia* species always occur in geothermal waters (Sada 2009, p. 4). Mehler et al. (2015, p. 172) studied 27 springs throughout Nevada and found groundwater nitrate levels between 0.004 and 1.77 milligrams per liter (mg/L) or 0.004 and 1.77 parts per million (ppm) and soluble reactive phosphorus between 0.002 mg/L to 0.49 mg/L (0.002 to 0.49 ppm), which are indicative of generally good water quality.

DO levels between 5.78 and 7.12 mg/L (5.78 and 7.12 ppm) were found to be negatively correlated with springsnail occurrence; as DO levels decrease, springsnail numbers increase

(Martinez and Thome 2006, pp. 13–14). Since water with low DO has high concentrations of carbon dioxide, there is greater primary productivity of periphyton (a primary food source) in these lower oxygen areas. Springsnails can be found in a variety of water quality conditions, including highly oxygenated waters, but the water must be relatively unpolluted (Mehlhop and Vaughn 1994, p. 69), meaning that it is essentially free from chemicals or other foreign substances that may cause harmful effects.

Adequate water quality is a habitat need of springsnails that may influence a population's condition (Hershler 1998, p. 11; Sada 2009, p. 3). Changes in temperature, DO, pH, conductivity, and other water quality metrics may impact the ability of a species to survive in a particular spring. For example, data for springs inhabited by the Page springsnail in Arizona showed lower DO [mean of 7.32 mg/L (7.32 ppm)] and lower conductivity [mean of 388 microSiemens per centimeter (µS/cm)] than springs without Page springsnails, and DO was directly correlated with pH (i.e., potential of hydrogen) (Martinez and Thome 2006, pp.11–12). We do not yet know, however, what the thresholds or limitations for these metrics are for the nine springsnail species evaluated in this report. Because the springs at Ash Meadows are typically outflows from deep regional carbonate aquifer, water quality parameters are likely to remain constant. To evaluate the current conditions of this factor, we assume that water quality parameters are adequate if the species is observed within a site.

3.3.2 Aquatic Vegetation and Substrate

Springs with perennial waters are surrounded with riparian and wetland vegetation that varies with elevation, soil type, discharge, and disturbance (Sada and Pohlman 2002, p. 4). Springs with minimal disturbance may be dominated by native sedges, rushes, grasses, willows, and mesquites (Sada and Pohlman 2002, p. 4), while springs with greater disturbance frequency may have minimal to no native vegetation. However, there may be situations where disturbed springs have varying abundance of nonnative aquatic vegetation, most common of which include (but are not limited to) tamarisk (*Tamarix* spp.), watercress, and Russian olive (*Elaeagnus angustifolia*).

Within a spring's source or downstream, *Pyrgulopsis* are commonly found among macrophytes (i.e., aquatic plants that grow in or near water), especially watercress, which often forms dense mats (Hershler 1998, p. 14). In large thermal springs, *Tryonia* may be found on bladderwort (*Utricularia* spp.) or on the bases of spikerush or bulrush (*Scirpus* spp.) (Hershler 1998, p. 14). The amount of vegetation needed by springsnails at a spring can vary. While most springs contain vegetation, a few springs with springsnail populations have minimal vegetation cover, although they contain other preferred substrata.

Substrata, the surface on which organisms live, is another element of springsnail microhabitat that varies by species. *Pyrgulopsis* are not usually found on soft sediments. They generally occur on hard substrates such as bedrock, gravel, and cobble, as well as on macrophytes like watercress (Hershler and Sada 1987, p. 837; Hershler 1998, p. 14; Sada and Pohlmann 2006, p. 8). Conversely, *Tryonia* generally occur on fine substrata, such as sand along banksides (Sada and Pohlmann 2006, p. 8; Sada 2008, p. 64). The occupied substrata not only contain biofilm food for all life stages, but also provide cover and sites for adults to lay eggs.

Sufficient vegetation and substrate are springsnail species needs that may influence all life stages of a springsnail and its population condition (Hershler and Sada 1987, p. 837; Hershler 1998, p. 14; Sada and Pohlmann 2006, p. 8). To evaluate current and potential future conditions of this factor, we categorized data from surveys (Sada 1987, entire; Sada 2020, unpubl.; USGS 2018, unpubl.; Service 2020, unpubl.). Given the best available information does not allow us to categorize each springsnail habitat by substratum type and by vegetation species, we categorized the known data using the following qualitative categories:

- *High*: Spring dominated by suitable vegetation and substrata for the species
- *Moderate*: Spring contains some suitable vegetation and substrata for the species
- *Low*: Spring predominantly lacks suitable vegetation and substrata for the species

3.3.3 Free-Flowing Water

An important factor of water quantity for springsnails is the continuity of naturally free-flowing water. In general, the presence of flowing water is required for robust populations. When spring sources are excavated and ponded, springsnail abundance diminishes rapidly (Sada 2017, p. 19). Based upon local site conditions, springsnails appear to thrive in spring ecosystems that contain free-flowing water without barriers, as compared to those with physical alterations or barriers. We consider barriers to include anthropogenic obstacles (e.g., impoundments), surfaces (e.g., culverts), and natural obstacles (e.g., high elevation areas, rocks, trees, and other obstacles above the water surface).

Free-flowing water is a habitat need of springsnails at all life stages, and may influence a population's condition. To evaluate the current conditions of this factor, we categorized information from survey reports and other sources as follows:

- *High*: Water is free-flowing without barriers
- *Moderate*: Water flows with partial barriers
- *Low*: Water flows are mostly or entirely blocked

Since springsnails are restricted to perennial aquatic habitats throughout their life cycle, the timing, frequency, and duration of a spring's flow regime is important to their viability (Hershler and Liu 2008, p. 92; Sada 2008, p. 59; Sada 2009, p. 2) (Fig. 3.2). Springsnails may be found in small seeps to large springs, so water depths can vary greatly (Hershler 1998, p. 11). The majority of springsnails occur in slow to moderate current (i.e., greater than 0 cm/sec to less than 40 cm/sec [greater than 0 in/sec to 16 in/sec]. They also occupy springs with discharge rates ranging from less than 60 L/min to 16,800 L/min (0.04 cfs to 10 cfs) (Sada 2009, pp. 3–4). Spring discharge should be continuous, the channel should not be obstructed, and water should be free-flowing for springsnails to persist.

3.3.4 Adequate Spring Discharge

Adequate spring discharge is a habitat need of springsnails that may influence a population's condition (Hershler and Liu 2008, p. 92; Sada 2008, p. 59; Sada 2009, p. 2). Adequate spring discharge is important for springsnail viability, and changes to discharge rates may impact the ability of a species to survive in a particular spring; however, the thresholds or limitations for "adequate" spring discharge for the nine springsnail species considered here are unknown. In the assessment of the current condition of this factor, we assume that spring discharge is adequate if the species is observed common or abundant within a site. However, for obligate aquatic organisms, decreases in discharge reduce habitat in the springbrook, and undoubtedly render springs more likely to desiccate during natural fluctuations in flow. Springs with few springsnails and lower discharges relative to those supporting common and abundant populations were regarded as moderate, low or dry condition.

3.4 Unknowns

Springsnails, as a group, have received relatively little attention regarding their ecology and conservation relative to other organisms. Much of the early investigations involved understanding taxonomic relationships. The advent of molecular taxonomy employed in the recent revisions of springsnails attests to the complexity and recent evolutionary diversification in this group. Outside of taxonomy, few ecological studies have directly addressed the species occurring on the Ash Meadows NWR, but major life-history traits and threats are presumed to be similar across Southwestern species, many of which documented by Hershler, Sada and colleagues. The great number and the remote nature of springs at Ash Meadows has resulted in most sites surveyed (with documentation) less than four times over the 25 years since their description. Only recently has springsnail conservation advanced academically (Hershler et al. 2014, entire), and stimulated more rigorous natural resource planning in Southwestern states (Hershler and Lui 2017, entire; Springsnail Conservation Team 2020, entire).

4.0 Factors That May Influence Species Needs

In order to analyze the current condition of habitats and springsnail populations, an understanding of potential factors impacting the physical and biological needs is necessary. These potential factors include how groundwater and surface water reach the Ash Meadows springs, and what threats influence the availability of groundwater. This includes how water is managed in Nevada and California, and how existing regulatory and voluntary conservation measures may reduce impacts from these threats.

4.1 Hydrology and Water Management Considerations

4.1.1 Hydrology

The more 60 springs in the Ash Meadows discharge area (including all springs associated with the Ash Meadows NWR and those nearby on private lands) represent a unique feature in the Amargosa Desert. Outside of the Refuge, the surrounding landscape is characterized by expansive xeric habitats, most of which are nearly devoid of surface water. Ash Meadows springs were formed because of a normal fault, referred to as the Gravity Fault, which bisects the Ash Meadows NWR. The Gravity Fault juxtaposes low-permeability clay on the west against permeable carbonate rock on the east (Winograd and Thordarson, 1975; p. C82). The low-permeability clay downgradient of the fault is a hydraulic barrier that forces groundwater to move upward and discharge at land surface, where the water is used by phreatophytes and aquatic species (Halford and Jackson, 2020, p. 129).

Groundwater discharging from Ash Meadows springs predominantly is sourced from recharge areas in the Spring Mountains and Sheep Range, which are east and southeast of the Ash Meadows discharge area (Stillings 2011, p.19). Groundwater flows in a west-northwest direction from recharge areas toward Ash Meadows springs primarily through carbonate rock. When groundwater reaches the impermeable Gravity Fault, the groundwater moves upward through permeable lenses within overlying basin fill to discharge at Ash Meadows springs.

The Ash Meadows discharge area occurs at the terminus of a hydrologically significant feature referred to as the "megachannel" (Winograd and Pearson 1976, entire). The megachannel is an 80 km (50 mi) long by 40 km (25 mi) wide area of fractured carbonate rock that has estimated transmissivities spanning from 20,000 to 2,000,000 ft^2/d (Halford and Jackson 2020, p. 136). High estimated transmissivities and confined aquifer conditions cause groundwater pumping signals to propagate large distances (24–32 km; 15–20 mi) in short timespans (less than 2 years) within the megachannel. Therefore, pumping from carbonate rock in the megachannel can significantly impact water levels and spring discharges in the Ash Meadows discharge area.

Halford and Jackson (2020, entire) used water-level and aquifer-test data to show that the Ash Meadows discharge area is hydraulically connected to the Alkali Flat–Furnace Creek Ranch groundwater basin through a narrow (3.2–8 km (2–5 mi)) wide corridor near well *AD-4* in the Amargosa Desert. The well *AD-4* corridor is northwest of the Ash Meadows NWR (Halford and Jackson 2020, p. 136). Within this corridor, permeable basin fill is juxtaposed against highly transmissive carbonate rock, which allows the propagation of drawdown (water-level declines from pumping) from the Amargosa Desert, through this corridor, into the megachannel, and southward toward Ash Meadows discharge area. The hydraulic connection between the Amargosa Desert pumping center and Ash Meadows discharge area is more attenuated, compared to direct pumping from the megachannel. This relationship exists because the well *AD-4* corridor is a limited area and basin fill in the Amargosa Desert has lower hydraulic diffusivity compared to the megachannel. Therefore, the effects of Amargosa Desert pumping are tempered, but still directly affect the groundwater levels in the Ash Meadows discharge area.

Devils Hole occurs within the Ash Meadows discharge area. Devils Hole is a collapsed limestone cavern that supports the endangered Devils Hole pupfish (*Cyprinodon diabolis*). The pupfish is likely the most imperiled fish species in Nevada, occurring in the smallest wild habitat of any vertebrate. The habitat of Devils hole is in the east-central part of the Refuge, between 0 and 8 km (5 mi) from the springs considered in this report. Therefore, an analysis of water-level declines in Devils Hole provides a proxy for understanding water conservation at Ash Meadows.

Effects of historical (1950–2020) and future (2021–2100) groundwater pumping on water levels in Devils Hole and spring discharges in the Ash Meadows discharge area were investigated by Halford and Jackson (2020, entire). Halford and Jackson (2020, entire) showed that historical groundwater pumping from within the megachannel; Indian Springs, Nevada; the Nevada National Security Site; and the central Amargosa Desert have caused water-level declines in Devils Hole between 1950 and 2020. Therefore, pumping from these geographic areas also likely has captured discharge from Ash Meadows springs. By 2018, historical groundwater pumping has captured about 500 acre-feet of the 18,500 acre-feet of predevelopment discharge from Ash Meadows springs (Halford and Jackson 2020, Table 13). A future "steady-pumping" scenario, which projected current (2020) pumping rates from 2021–2100, resulted in an estimated capture of 1,100 acre-feet of discharge by 2100 from Ash Meadows springs (Halford and Jackson 2020, Table 13). This base-level scenario was estimated to reduce water levels in Devils Hole approximately 0.03 m (0.1 ft) per decade over this time period.

In addition to the base or steady-state pumping scenario above, Nelson and Jackson (2020, entire) extended the findings above to specifically model how increased groundwater withdrawal scenarios potentially affect Devils Hole and the Ash Meadows drainage area. This report simulated three additional scenarios where higher pumping volumes and pumping locations within the megachannel might further affect long-term water levels from 2010-2120. The author's scenarios were developed in coordination with state and Federal agencies to capture potential water use, and applied a constant level of recharge estimated for the region. The increased water use specified in the models were not based on specific future plans for water development in the area. The first and second scenarios above the base-level simulated increases of 13 and 6 percent, respectively, in capture due to pumping, and resulted little reduction in water level relative to base-level for Devils Hole (Nelson and Jackson 2020, p. 26.). The third scenario that increases pumping by 94 percent showed a drastic decline in water level at Devils Hole. Still, it remains valuable to consider the potential reduction in water levels estimated by the continuation of pumping at the current rate. It is important to note that Nelson and Jackson (2020) used a constant rate of recharge based on long-term average precipitation for the region and that actual recharge has been greater that this over the last 20-30 years such that water levels in Devils Hole have been increasing despite historical and current regional groundwater pumping. Additionally, with regard to changes in water level discussed above, there is some uncertainty to consider with respect to individual spring discharges across Ash Meadows. Specific hydrologic connections associated with individual spring sources has not been investigated. In the absence of spring-specific hydrology information, it is expected that sources at high elevation and low discharge might be more vulnerable to general reduction in water levels.

4.1.2 Water Management

Water management in Nevada is administered by the State Engineer from the Nevada Division of Water Resources (NDWR). Groundwater management is divided into, and is administered by hydrographic area (Nevada Department of Conservation and Natural Resources (DCNR) 2017, entire). To ensure the amount of groundwater withdrawn from a hydrographic area over a period of time does not exceed the long-term recharge of the basin, the State designates basins to reflect water resources based on the extent of water development and water use, and the appropriation of water rights (NDWR, entire; California Department of Water Resources 2020, entire). Any use of water requires a state permit with two exceptions. The first exception is that domestic wells do not require permits in either state, although in Nevada, this is true only if the well uses less than 6,814 L (1,800 gallons (g)) of water per day (Nevada Division of Water Planning 1999, p. 8-3). Although domestic wells do not require a permit, some oversight is provided by the requirement of a permit to drill a new well (Welden 2003, p. 8). The second exception is relevant only in Nevada where permits are not required for those uses that pre-date water law requirements (DCNR 2017, entire).

In Nevada, the Nevada State Engineer (NSE) identifies basins as designated or not designated based on the concept of perennial yield. Perennial yield is defined as the maximum amount of groundwater that can be withdrawn each year over the long-term without depleting the groundwater reservoir (DCNR 2017, entire) and is measured in acre feet per year (afy). Perennial yield cannot be more than the natural recharge of the groundwater reservoir and is usually limited to the maximum amount of natural discharge. In some areas, natural discharge in the form of spring discharge may be appropriated already as surface water, although the perennial yield estimate may still include this water (DCNR 2017, entire). Groundwater seepage or discharge may help sustain ecosystems in other areas (DCNR 2017, entire).

The Nevada State Engineer identifies a basin as designated if a determination is made that further administration of the basin is needed (Welden 2003, p. 8). This typically occurs when water use is approaching or exceeding the recharge (Welden 2003, p. 8). By identifying a basin as designated, the NSE is granted additional authority in the administration of the groundwater resources within the designated basin. In basins where groundwater is being depleted, the NSE may issue orders, regulations, or rules to ensure that water use and recharge are balanced (Welden 2003, p. 8). Orders, regulations, and rules may include identifying preferred water uses, prohibiting the drilling of new domestic wells, monitoring pumping inventories, declaring critical management areas, and using other management tools (Welden 2003, p. 8; DCNR 2017, entire).

In 2014, the State of California passed the Sustainable Groundwater Management Act (SGMA) which provided direction of forming locally organized groundwater sustainability agencies and locally developed groundwater sustainability plans as well as the halting of overdraft in groundwater-dependent regions (Wyckoff and Floyd 2016, p. entire). The California Department of Water Resources is responsible for implementing the SGMA as well as the characterization of California's groundwater basins through updates to California's Groundwater, Bulletin 118 (California Department of Water Resources 2020, entire). None of the groundwater basins occupied by the Amargosa tryonia are identified as critically overdrafted in Wyckoff and Floyd (2016, p. 12).

The springs where the nine springsnails occur are included in Hydrographic Area (HA) 230, the Amargosa Desert (also includes parts of California), and are located within a designated basin (O-724). The estimated perennial yield for this basin is 24,000 afy. For water year 2019, the committed resource totaled 27,874 acre-feet, with estimated pumpage of approximately 17,005 acre-feet for HA 230. This value includes an estimated 255 acre-feet pumped from exempt domestic wells (NDWR 2019, p. 1). In addition to the system of appropriated groundwater rights, the immediate area around the Ash Meadows NWR is protected by NSE Order 1197A (NSE 2018). This order protects the Refuge (by consequence of Devils Hole) from new applications for wells and changes in points of diversion on existing water rights that would occur within 40.2 km (25 mi) of Devils Hole. This order was enacted to protect the Federal water right to maintain a specified water level in Devils Hole. This order represents an increase in protection from the 2008 Order 1197, specifying similar regulations beginning at 20.1 km (10 mi) from Devils Hole.

These measures to conserve water in the Ash Meadows discharge area by the NSE follow a long history of protective water management. During the early 1970s, extreme groundwater development occurred, and resulted in drastic reductions in both water-level and spring discharge at Ash Meadows (Dudley and Larson 1976, entire). In 1976, the Supreme Court upheld a decision to maintain suitable habitat in Devils Hole for the Devils Hole pupfish in *Cappaert v. the United States*. The mandated water level (minimum) is 0.82 m (2.7 ft) below a reference point in Devils Hole (Deacon and Williams 1991, p. 79). The mandate requires the water to be maintained to ensure the survival of the fish, irrespective of whether pumping or a combination of climate and pumping contribute to water-level decline. The impacts of groundwater withdrawal (at historically minimum levels) caused reductions in all of Ash Meadows springs, including both the largest springs (e.g., Fairbanks and Crystal springs), and relatively smaller springs (Point of Rocks, Five, and Collins Ranch springs), some which were reported dry (Halford and Jackson 2020, p. 87). However, some springs showed relatively small reductions in discharge, and suggest that individual spring response varies.

Still, the most recent modeling of Halford and Jackson (2020, entire) outlines the presence of a megachannel, where pumping within which likely affects the Ash Meadows discharge area; the effects of which are not directly related to distance between pumping and the spring source, but instead governed by whether pumping occurs inside or outside the megachannel boundaries.

4.2 Threats Considered But Not Carried Forward

We considered the potential impacts from parasitism, disease, and collection because they are known to impact similar springsnail species and therefore, may impact the springsnail species evaluated in this SSA report. However, the best available scientific and commercial information does not indicate significant impacts from parasitism, disease, or collection specific to these species. Therefore, these potential threats are not analyzed further in this evaluation.

4.2.1 Parasitism and Disease

Researchers have documented parasitism in other freshwater snail species, so logically it may also impact the nine springsnail species in this SSA report. Parasitic (e.g., trematode) infections can be prevalent in some freshwater snail species with impacts to the individuals and potentially to populations. For example, Taylor (1987, p. 47) found that trematode infestation and incidence of parasitic castration are high in dense populations of springsnails in New Mexico. However, following our evaluation of all potential threats, we found no evidence that springsnails are affected by disease and no information to document impacts from parasitism as a threat to the nine species evaluated in this SSA report.

4.2.2 Collection

Springsnails are occasionally collected for purposes associated with spring and springsnail surveys. Collection may be necessary to provide voucher specimens or verify the species' identity. Martinez and Sorenson (2007, p. 28) detected significant differences in the total size of springsnail populations across sampling periods. Sampling without replacement caused a transitory decline in total population size of each organism, though springsnails became locally abundant again the following year (Martinez and Sorenson 2007, p. 28). Springsnails may also be incidentally collected when vegetation or substrate is removed from springs or springbrooks. This likely occurs during restoration activities (e.g., removing dense vegetation within a spring) or from vegetation removal for personal use (e.g., removing watercress to eat). The best available information suggests that no collection is occurring at any spring that affects the nine springsnail populations. Therefore, we will not discuss collection as a potential threat further in this report.

4.3 Threats Carried Forward

We determined the following threats (Fig. 4.1) may impact specific springsnails needs (Chapter 4) and ultimately the resiliency of springsnail populations (Chapters 5 and 6). Not all threats have been documented at all springs. In each section, we identify at which springs threats have been observed and which springsnail species may be impacted. We also describe the general potential effects of these threats on the needs of springsnails. Additional specific information on impacts to each spring location and springsnail population, if applicable, is discussed in Chapters 5 and 6.

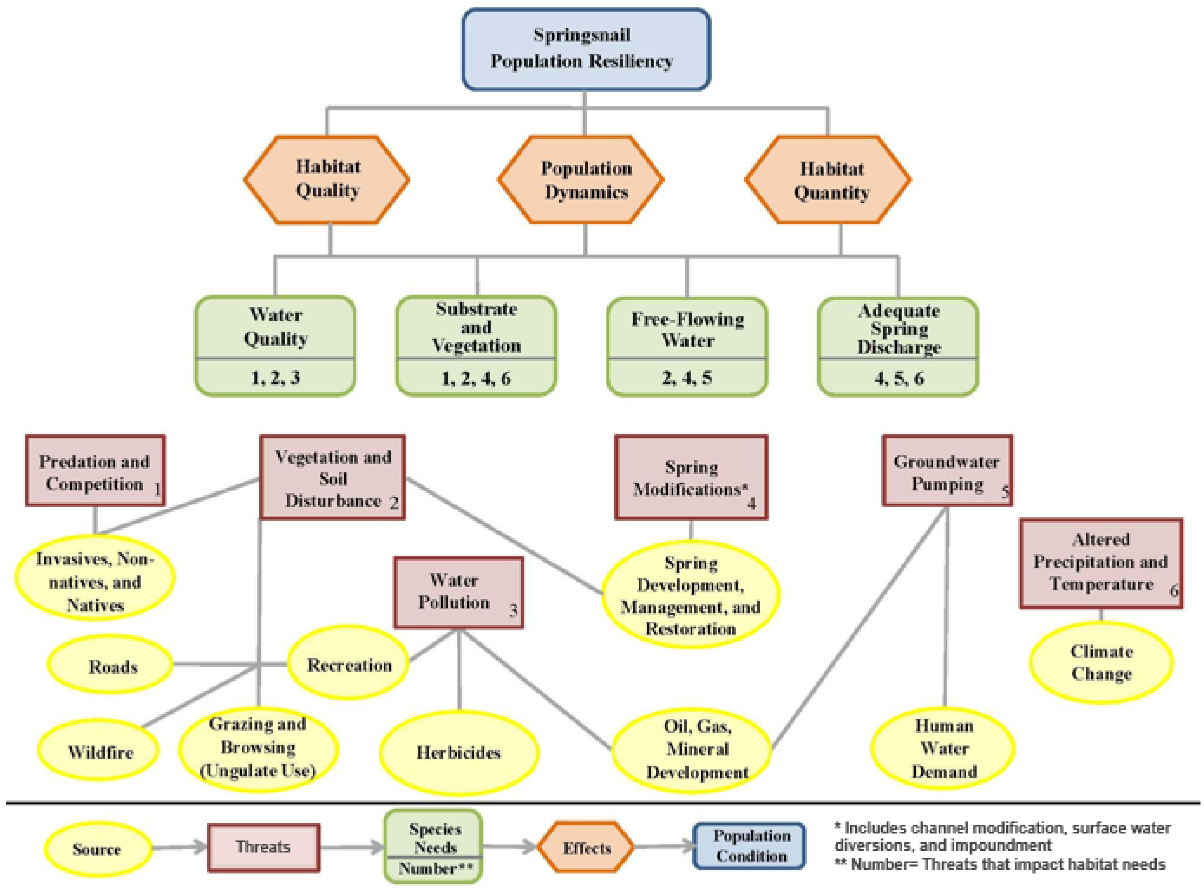


Figure 4.1. Illustration identifying threats, sources of those threats, species needs, effects, and population condition for the nine springsnails evaluated in Ash Meadows and Amargosa Valley, Nevada and California.

4.3.1 Predation and Competition

Predation and competition have been documented in similar species of springsnails and likely occur where invasive, nonnative, and native species co-occur. Potential predators and competitors have been documented at one or more springs or spring provinces, potentially impacting the following species: median-gland springsnail, Crystal springsnail, Fairbanks springsnail, distal-gland springsnail, Amargosa tryonia, and minute tryonia.

Invasive and nonnative species, and to a lesser degree native species, are known or presumed predators of springsnails and compete for resources such as food and space. These species can indirectly affect springsnails by changing ecosystem function (Brown 2008, p. 489; Lysne 2008, pp. 466–467; Sada 2017, p. 11). Ecosystem changes include disruption of the algal component, nutrient recycling, and fluxes in bacterial production as described by Mehler and Acharya (2014, p. 93). Invasive and nonnative competitors can also change the dominance relationships among gastropods and result in major losses of native species (Covich 2010, p.

191).

We found no documented observation of predation of any of the nine species in this assessment; however, we assume predation occurs because it has been observed in other *Pyrgulopsis* species in similar environments with the same predator species. Many different types of predators can consume small snails that are typically less than 4 mm (0.2 in) shell length (Covich 2010, p. 195). Natural predators of springsnails include waterfowl, shorebirds, amphibians, fishes, crayfish, leeches, and aquatic insects (Martinez and Thome 2006, p. 9). Damselflies (Zygoptera) and dragonflies (Anisoptera) have been observed feeding on snails (Mladenka 1992, pp. 81–82). Important nonnative species that have extirpated spring-dwelling taxa in the southwestern U.S. include crayfish (mostly *Procambarus* spp.), mosquitofish (*Gambusia affinis*), red-rimmed melania (*Melanoides tuberculata*), mollies (*Poecillia* sp.), goldfish (*Carassius auratus*), cichlids, and bullfrogs (*Rana castebeiana*) (Sada 2017, p. 11).

Pyrgulopsis species appear to be negatively affected in various parts of the Southwest by introduced crayfishes that feed on aquatic snails (Hershler 1998, p. 14; Sada and Vinyard 2002, p. 277). In a study within our analysis area (i.e., Ash Meadows, Nevada), springs containing crayfish consistently had fewer animal species and contained little to no endemic springsnails (Kilburn 2012, p. 43). Animal material was present in 93 percent of crayfish stomachs analyzed, with one gut filled entirely with native springsnails and native riffle beetle larvae (Kilburn 2012, p. 43). This level of predation could affect the population dynamics and substantially reduce the size of springsnail populations. Many springs assessed in this report readily accessible by the public are most vulnerable to introduction of crayfish and other springsnail predators and competitors.

Several families of fish are known to prey on springsnails in the U.S and Canada, including the families Acipenseridae, Cyprinidae, Catostomidae, Ictaluridae, Centrarchidae, and Percidae (Johnson 2013, p. 248). Field experiments in Cuarto Cienegas, Mexico, demonstrate that hydrobiid snails (such as *Mexipyrgus churinceaus*) increase threefold in density when predatory fishes were excluded (Covich 2010, p. 204). Remnants of Page springsnail shells have been reported in analyses of stomach content of mosquitofish from the Oak Creek Springs complex (= province) in Arizona (Raisanen 1991, p. 71). Within the analysis area at Ash Meadows, such as Crystal and Fairbanks Springs, mosquitofish are present. Although predation is possible in these areas, none has been documented to date. Additional research is needed to determine if there are any population-level effects of nonnative fish on these species.

Some predator species are known to kill snails by penetrating the shell opening, such as some leeches and aquatic insects (Covich 2010, p. 207), which are species known to occur within range of springsnails assessed in this report. When this type of predation occurs, they leave no trace and their impact on both individuals and populations is difficult to determine in remains of modern or fossil shells (Covich 2010, p. 207).

Springsnails that co-occur in large spring systems with greater habitat heterogeneity appear to be facilitated by spatial habitat segregation (Brown 2008, pp. 488–489); this segregation suggests a competitive basis for substrate use. For example, Sada (2008, p. 60) describes an assemblage of native springsnails and the nonnative red-rimmed melania in southern Nevada, which includes several areas at Ash Meadows. In general for Ash Meadows, springsnails occupy a wide diversity of habitats, but each species exhibits habitat preferences for a range of depths, velocities, temperatures, or substrates. Habitat niche overlap occurs, but varies among species and habitats. Thus, competitive interactions seem complex at Ash Meadows. In some cases the impacts at appear to minimally influence the structure and distribution of some species in this report, yet others are likely to be negatively affected.

Invasive snails affect native snails directly through competition for food and space or indirectly through changes in ecosystem function or parasite populations (Brown 2008, p. 489). Additional stress from competition is posed by invasive gastropods including the red-rimmed melania (*Melanoides tuberculata*) and New Zealand mudsnail (*Potamopyrgus antipodarum*), which have recently spread across large portions of the West (Hershler 2014, p. 5), including springs at Ash Meadows. However, the effects of red-rimmed melania may not always be large. In others systems outside of Ash Meadows, on habitat heterogeneity in the springbrook may provide sufficient partitioning to coexist with native taxa (Sada 2017, p. 67). Both of these invasive species primarily reproduce asexually and frequently achieve high densities at localities where they co-occur with springsnails (Hershler 2014, p. 5). Red-rimmed melania are known to competitively displace native gastropods, posing concern for endemic populations of springsnails in New Mexico (New Mexico Aquatic Invasive Species Advisory Council 2008, p. 20). Riley (2008, p. 509) showed a significant reduction in the growth rate of the native Jackson Lake springsnail in the presence of the New Zealand mudsnail in the Snake River drainage. Although these two studies involve species of springsnail outside the analysis area, springs in our analysis area that harbor these invasive or nonnative competitors can result in one or more of the nine springsnails being at greater risk of experiencing individual-level or possibly population-level impacts from predation.

In summary, springsnail predation and competition are potential threats to all nine springsnail species; at least two of nine springsnail species co-occur with nonnative fish and crayfish. The red-rimmed melania occurs at springs occupied by all nine springsnails. Competition between red-rimmed melania and springsnails appears to minimally influence the abundance of endemic springsnails at some sites (e.g., Fairbanks and Crystal springs), but it is unknown the level of impact at other sites where red-rimmed melania are abundant and springsnails are not. The current level of impact of red-rimmed melania has not been studied at Ash Meadows.

4.3.2 Vegetation and Soil Disturbance

The primary cause of imperilment for springsnails is loss or alteration of habitat (Lysne *et al.* 2008, p. 464). Sources of stress such as wildfire, roads, recreation, and grazing and browsing (ungulate use) contribute to vegetation and soil disturbance at springsnail locations evaluated in this SSA Report. In this section, we generally describe how vegetation and soil disturbance can affect springsnail needs, which include water quality, substrate and vegetation, and free-flowing water, followed by specific ways each stressor affects springsnails. Abele (2011, p. 5) found that spring data collected in Nevada during the 1990s and again in 2007 and 2008 showed little difference in the overall condition of springs. However, by 2011, with greater surveying effort, few springs within the Great Basin were found to be unaltered by diversion, recreation, or incompatible livestock use (Abele 2011. p. 5), and characteristics of only 20 percent of springs were relatively natural (Abele 2011, p. 6).

Sada *et al*. (2015, p. 4) determined that there are few studies associated with spring systems and how they respond to human disturbance. Fleishman *et al.* (2006, p. 1,091) found that species richness (total number of taxa in a sample) of spring-associated perennial plants and cover of native plants tend to decrease as intensity of disturbance increases, whereas species richness (but not cover of nonnative plants) tend to peak with intermediate disturbance, which include grazing, recreation, and water diversion). Spring-fed aquatic and riparian communities may be resistant to minor disturbance but are affected by higher levels of disturbance (Sada *et al.* 2015, p. 3). This is consistent with a basic tenet of ecological processes whereby the effects of disturbance on a system is a function of its magnitude, duration, and frequency. Ecological systems are characteristically resistant and resilient to low magnitude disturbances that are short-term and infrequent, but they may be functionally altered when a disturbance is frequent, long lasting, or exceedingly large (Sada *et al.* 2015, p. 3). Anthropogenic disturbances may also modify material flow and nutrient cycling through food webs (Sada *et al.* 2015, pp. 2–4). Species needs affected by soil and vegetation disturbance include aquatic vegetation and substrate (including bank cover and canopy cover). Vegetation and substrate provide breeding, feeding, and cover for springsnails. Changes in bank or canopy cover may affect thermal protection and primary production for springsnail food and shelter needs.

In Colorado Plateau springs, Weissinger *et al.* (2012, p. 393) examined disturbance and biological and hydrological characteristics of springs impacted by livestock and vehicle use and found that taxonomic richness of vegetation was highest in moderately disturbed sites and lower in highly disturbed springs. They also observed that disturbance reduced vegetative cover, increased water temperature, and changed substrate composition but found no effect on nutrients, DO, pH, electrical conductance, or spring discharge (Weissinger *et al.* (2012, p. 393). In a similar study, Sada *et al.* (2015, p. 43) found no relationship between disturbance and taxonomic richness for Nevada springs. Therefore, within our analysis area, we considered the magnitude of potential impacts from vegetation and soil disturbance.

Sada and Lutz (2016, p. iii) found that moderately or highly degraded springs were most common on Bureau of Land Management (BLM) land, followed by private lands, U.S. Forest Service (USFS), and finally Service (National Wildlife Refuge) lands. With the exception of one species, Amargosa tryonia, the remaining eight species occur on lands managed within the Ash Meadows NWR. Many of these springs in this assessment appear to have stabilized from anthropogenic disturbance or following restoration activities of the Service.

4.3.2 Water Pollution

Although hydrobiid snails as a group occur in a wide variety of aquatic habitats, each species is usually found within relatively narrow habitat parameters, and is likely sensitive to water quality (Sada 2008, p. 59). Potential sources of water pollution documented at springsnail locations within our analysis area that may impact current and future conditions of water quality include recreation and herbicide application. The level of effect these sources may have on water pollution has not been measured or sampled; however, we assume some level of water pollution is occurring if recreation or herbicide application has been documented at or near a spring.

4.3.3.1 Water Pollution from Recreation

In addition to habitat disturbance from recreation (described previously in Chapter 4), recreational activities may contribute to water pollution at springs that supports springsnail populations. Recreation, such as bathing, is a threat to spring ecosystems if chemicals are added to the system (Mehlhop and Vaughn 1994, p. 72). The source of these chemicals may include soap or sun protection products. We assume that if a spring is known to be used for recreational bathing, some level of water pollution is occurring, although no water quality sampling has been completed to evaluate this. The fact that springsnails have persisted suggests that at historical and current levels, no population-level impacts have occurred. In addition, Sada (2017, entire) reports that springsnails tolerate low to moderate levels of these activities with no apparent population- or species-level effect to their overall numbers and distribution, particularly if the impacts are short-term. While most springs in this report occur on the Refuge where swimming is not allowed, the impacts from recreation may be present on private land.

4.3.3.2 Water Pollution from Herbicides

The application of herbicides on lands administered by state or Federal agencies occurs under strict regulations and procedures (e.g., Service 2006, p. 41). Herbicide application on Federal land is also evaluated in accordance with the National Environmental Policy Act of 1970 (NEPA), while herbicide use on private land does not typically require NEPA analysis. Standard stipulations for herbicide use near riparian areas on Federal land typically require the use of a selective herbicide that is safe for uses in riparian zones and near aquatic sites using hand application methods.

We expect any potential effects to springsnails from herbicides to occur at the individual, spring, or population level as opposed to rangewide impacts. The likely method of exposure would be from aerial drift or runoff from treated vegetation after a rain event, since aquatic herbicides are not typically applied to springs or streams. If herbicides are applied on the Ash Meadows NWR, use would follow the U.S. Environmental Protection Agency application schedules designed to minimize potential impacts to non-target plants and animals (e.g., Service 2006, p. 42). We cannot assess the potential impact of herbicides on privately-owned springs, but we found no information that application of herbicide at springs assessed in this report has occurred.

4.3.3 Spring Modifications

Spring modifications include channel modification, surface water diversions, and impoundment at springs. Such modifications may occur for development, management, or restoration purposes and have been documented at the majority of springs and spring provinces, and therefore, all nine springsnail species have one or more populations potentially impacted from this threat historically.

Human alterations of springheads, to concentrate or divert discharge, negatively impact spring systems and invariably result in loss of biota (Unmack and Minckley 2008, p. 20). Spring developments may result in water diversion, impoundments, or channel modification. Documented examples of springs in Death Valley National Park that were developed for municipal water use have changed aquatic and riparian habitats and eliminated several populations of endemic macroinvertebrates (Sada and Herbst 2006, p. 1). For springs assessed in this report, most springs in Ash Meadows have been altered to some degree by development. The Refuge has been working to remove barriers and repair flow paths since its establishment.

Surface water diversions are sources of multiple threats to springs including: altering physical integrity, creating conditions that favor nonnative aquatic species, or degrading habitat conditions for native riparian vegetation. Additionally, the presence of pipes, dikes, dams, impoundments, channel modifications and dredging, and spring boxes indicate further stress in the form of spring diversions and loss of occupancy at some sites. Although surface water diversions can cause stress to springs and springsnails, as indicated above, populations of springsnails in historically disturbed habitats can recover if the disturbance is low in magnitude and infrequent (Sada 2017, p. 22).

Spring systems can also recover from vegetation and soil disturbances that occur from restoration activities. For example, historical impoundments can be removed in order to restore habitat for aquatic species. This entails removal of the impoundment often followed by channel modification in order to get the system to return to its natural channel, which may no longer be present. While restoration is a large source of stress to a spring system and springsnails, there is usually an overall benefit to springsnails by improving all of the species needs within a spring (water quality, substrate and vegetation, free-flowing water, and adequate spring discharge).

Although some spring-dependent species may prefer deeper water that is often associated with impoundments, springsnails primarily rely upon the natural physical integrity of an undammed system. All impounded springs are considered disturbed because flow has been interrupted and functional characteristics of the aquatic system have likely been altered.

Spring discharge in the western U.S. has been primarily affected by surface diversion from spring sources and springbrooks that causes reduced spring discharge. In extreme cases, springs and springbrooks are dried and all aquatic life is extirpated. Springs and springbrooks may not completely dry when diversions leave water in the system, but decreased discharge affects springbrook habitat and the structure and functional characteristics of the benthic macroinvertebrate community, which includes springsnails.

Aquatic habitat and productivity are affected by diversion in a number of ways. As discharge is reduced, springbrook length and wetted width and depth decrease. Decreasing the volume of water also alters thermal characteristics of the springbrook, as well as aspects of water chemistry such as pH and DO concentration. Consequences of these incremental changes include reduced productivity, habitat heterogeneity, and benthic macroinvertebrate microhabitat availability (Sada et al. 2015, pp. 45–46).

Riparian vegetation has an early and evident response to a reduction in springflow. Plants occurring in spring outflows are adapted for life in waterlogged soil; however, as water levels decline, soil dries and becomes aerated, which facilitates invasion of forbs, shrubs, and trees. New water depths and soil conditions may also allow stands of cattails (*Typha* spp.) and reeds (*Phragmites* spp.) to expand, sometimes reducing or eliminating open water (Unmack and Minckley 2008, p. 24).

In summary, spring modifications may include surface water diversion, impoundment, or channel modification, including dredging. These spring modifications affect springsnail needs by reducing springbrook discharge length, wetted width and depth (unless ponded), and open water needed for plant productivity, which provides food and shelter. Because the thermal and chemical properties of water are influenced by water depth and flow, alteration of these properties may affect water quality. The level and effect of spring developments across all the locations analyzed in this report range from an absence of spring modifications to potentially significant impacts. Details related to specific locations and species are presented in Chapter 5 where applicable.

4.3.4.1 General Impacts from Groundwater Pumping

Increased groundwater pumping in Nevada and southeastern California is primarily driven by human water demand for municipal purposes, irrigation, and development for oil, gas, and minerals. In this section, we first describe general impacts from groundwater pumping on springsnails and their habitat. We use the term *human water demand* to describe groundwater pumping and withdrawal to support residential and metropolitan development. We then describe *additional impacts from oil, gas, and mineral development*, a phrase we use to encompass all phases (i.e., exploration, development, production, and reclamation) of these types of projects. Finally, we describe specific projects that have occurred or are proposed that may impact springs in which one or more of the nine springsnail species occur.

Many factors associated with groundwater pumping can affect whether or not an activity will impact a spring. These factors include the amount of groundwater to be pumped, period of pumping, the proximity of pumping to a spring, depth of pumping, and characteristics of the aquifer being impacted. Depending on the level of these factors, groundwater withdrawal may result in no measureable impact to springs or may reduce spring discharge, reduce free-flowing water, dry springs, alter springsnail habitat size and heterogeneity, or create habitat that is more suited to nonnative species than to native species (Sada and Deacon 1994, p. 6). Reduced spring discharge may also decrease springbrook length and wetted width as well as diminish the total area of substrate and amount of primary and secondary production, thus adversely affecting food resources for springsnails (Sada 2017, pp. 7–8). Excessive groundwater withdrawal can lower the water table, which in turn will likely affect riparian vegetation (Patten 2008, p. 399).

Excessive groundwater withdrawal can be difficult to monitor and reverse due to inherent delays in detection of pumping impacts, the subsequent lag time required for recovery of discharge at a spring (Bredehoeft 2011, p. 808), and the difficultly of retroactively regulating groundwater extraction. Groundwater pumping initially captures stored groundwater near the pumping area until water levels decline and a cone of depression expands, potentially impacting water sources to springs or streams (Dudley and Larson 1976, p. 38). Spring aquifer source and other aquifer characteristics influence the ability and rate at which a spring fills and may recover from groundwater pumping (Heath 1983, pp. 6 and 14). Depending on aquifer characteristics and rates of pumping, recovery of the aquifer is variable and may take several years or even centuries to recover (Halford and Jackson 2020, p. 70; Heath 1983, p. 32). Yet where reliable records exist, most springs fed by even the most extensive aquifers are affected by exploitation, and springflow reductions relate directly to quantities of groundwater removed (Dudley and Larson 1976, p. 51).

The most extreme effects of groundwater withdrawal on springsnails are habitat desiccation and extirpation or extinction. If groundwater withdrawal occurs but does not cause a spring to dry, there can still be adverse effects to the springsnails or their habitats. Reduction in springflow both reduces the amount of water and amount of occupied habitat by altering microhabiat characteristics of the springbrook (Morrison et al. 2013, p.11). If the withdrawals also coincide with altered precipitation and temperature from climate change, even less water will be available. Cumulatively, these conditions could result in a delay in groundwater recharge at springs, which may then result in a greater impact on springsnail populations than the effects of the individual threats acting alone. Across the Ash Meadows springs, discharge varies greatly, with some springs sufficiently low at present likely due to a combination of influences, both natural and anthropogenic. Therefore, any future effects of groundwater withdrawal are of significant importance.

4.3.4.2 Municipal Water Use and Irrigation

Groundwater pumping for human water demand and associated development projects can impact springs and spring provinces where springsnails occur. The current rate of groundwater withdrawal from a hydrographic area indicates where water demands may increase in the future. Increased demands and use of water could impact all springs where springsnails occur. These trends may also indicate spring impacts due to historical events. Estimates for the amount of groundwater pumped by residential or domestic wells provide some trend information.

Nearby to Ash Meadows, historical groundwater pumping in the Las Vegas and Pahrump Valleys resulted in reductions to groundwater elevations, which affected springs and springsnails in the past (Deacon 2007, p. 688). Groundwater elevation declines of up to 30 m (98 ft) in Pahrump Valley (Harrill 1986, p. 22) and up to 91 m (299 ft) in Las Vegas Valley (Burbey 1995, p. 9) were documented in 1975 and 1990, respectively. As a result of pumping events, several springs went dry in Pahrump Valley during the 1970s, including Manse Springs (Pahrump), which led to extirpation of a local population of the Spring Mountains pyrg (*Pyrgulopsis deacon*) in 1975 (Hershler 1998, p. 25). These examples indicate groundwater pumping may be an important threat to springs and springsnail populations.

While some variability in well withdrawal trends exists, in general, an increase in groundwater withdrawals has occurred in most hydrographic areas since the 1950s (Green et al. 2011, p. 543). This likely reflects increasing human populations and water demands for human use. Because human populations in Nevada are expected to continue to increase (Garfin et al. 2014, p. 470), water demand would likely also increase. This increased demand represents a potential added pressure to the water that provides habitat for all springsnails in this SSA report. As discussed above in Chapter 4.1.1, Halford and Jackson (2020, entire) estimate that the declines from predevelopment levels at Devils Hole are influenced by groundwater pumping, initially by Cappaert Enterprises (1969–1980) and other (NNSS) megachannel pumping, and predominantly due to nearby groundwater pumping in the central Amargosa Desert by 2018. They further predicted that continued steady-state pumping will result in declines in water level at Devils Hole. We recognize that this is a potential future threat, and thus results are incorporated in the future *Scenarios 2* and *3* (see Chapter 6).

Although the relationship between regional groundwater pumping and its direct effects on the water availability in the Ash Meadows area were established in recent studies (Halford and Jackson, entire; Nelson and Jackson, entire), the absolute amount of water discharging from springs in the future is uncertain. The future discharge depends both on groundwater pumping, and the future recharge to the system. The variation in recharge due to climate change was not the focus of the above investigations, which was to explain the connection between pumping and water levels. Therefore, changes in precipitation will concurrently affect the ultimate discharge at springs.

4.3.4.3 General Impacts from Oil, Gas, and Mineral Development

We are unaware of any oil, gas, or mineral development project locations. Oil, gas, and mineral development on public land would likely occur in areas administered by the Bureau of Land Management (BLM), and could potential interact with springsnails on the Ash Meadows NWR. In southern Nevada, the analysis area includes BLM lands managed by the Southern Nevada and Pahrump district offices.

Hydraulic fracturing (fracking) is sometimes used as part of oil and gas development projects and has the potential to both contaminate and consume water resources (Al-Bajalan 2015, pp. 4–6; Mehany and Guggemos 2015, p. 172). Fracking is a process that occurs after a well is drilled but before it begins producing oil or gas. During fracking, an oil and gas company uses concentrated explosions to fracture the geologic formation containing the oil or gas. Subsequently, a proprietary mixture of chemicals and water is pumped at high pressure into the formation along with sand to open the pore space of the rock and release the oil and gas.

Most fractured wells will consume 10.2 to 14.7 million L (2.7 to 3.9 million g) of pressurized water along with dozens of chemicals constituting 2 to 3 percent of the total volume (Sovacool 2014, p. 257). Water resource contamination can occur as a result of unlined and leaky storage pits of fracturing liquids, accidental blowouts (uncontrolled escape of fluid from well to surface), improper disposal of fracking fluids, faulty well cementing, release of natural gas (methane), and the possible connection of deep fractures with surface water (Mehany and Guggemos 2015, pp. 172–173; Al-Bajalan 2015, pp. 3–4).

Fracking and shale gas production can contribute to increased seismicity and earthquakes, though on a smaller scale than major catastrophic earthquakes (Sovacool 2014, p. 260); however, the effects of increased seismicity and earthquakes on springs and springsnails are not known.

Springs may be impacted by oil and gas development if fracking is used and groundwater pumping occurs; the effects of groundwater pumping on springsnails are discussed above. A considerable number of organic and inorganic compounds have been detected in shallow and deep drinking water outside the analysis area due to fracking chemicals (Al-Bajalan 2015, p. 6). If contaminants from fracking enter the groundwater and emerge at spring sources, springs and springsnails would likely be affected, even those at some distance from the fracking site.

4.3.4.4 Altered Precipitation and Temperature from Climate Change

The southwest region where the springsnail sites occur is one of the hottest and driest areas of the United States, and climate change is likely to exacerbate these conditions. Changes in climate have already been observed in this region and are expected to continue. Average annual temperatures have increased almost 1.1 °C (2 °F) over the last century (Garfin 2014, p. 464), and an additional increase of 1.9 to 5.3 °C (3.5 to 9.5 °F) is predicted to occur by the year 2100 (Walsh 2014, p. 23). In recent decades, reductions in precipitation and winter snowpack have been observed, and this pattern is expected to continue (Garfin 2014, p. 465; Fig. 4.2). The frequency and intensity of these reductions have increased on a global scale (IPCC 2014, p. 51), and climate change is projected to reduce surface and groundwater resources in most subtropical deserts (IPCC 2014, p. 69). The majority of model simulations based upon future climatic conditions predict a drying trend throughout the Southwest during the 21st century (Seager 2007, pp. 1,181–1,184). Overall anticipated climate change impacts for the region include: warmer temperatures, decreased precipitation, fewer frost days, longer dry seasons, reduced snowpack, and increased frequency and intensity of extreme weather and disturbance events (heat waves, droughts, storms, flooding, wildfires, insect outbreaks; Archer and Predick 2008, pp. 23–25; Seager 2007, p. 1,183; U.S. Global Change Research Program (USGCRP) 2009, p. 131; Garfin 2014, p. 463; Walsh 2014, p. 36). General circulation model (GCM) projections indicate a marked reduction in spring snow accumulation in mountain watersheds across the southwestern United States (Fig. 4.2, top panel) (Garfin 2013, pp. 117–118). More rain and less snow, earlier snowmelt, and to some extent, drying tendencies, cause a reduction in late-spring and summer runoff (Fig. 4.2, middle panel). These effects, along with increases in evaporation, result in lower soil moisture by early summer (Fig. 4.2, bottom panel).

Both human settlements and natural ecosystems in the southwestern U.S. are largely dependent on groundwater resources, and decreased groundwater recharge may occur as a result of climate change (USGCRP 2009, p. 133). Furthermore, the human population in the southwest is expected to increase 70 percent by mid-century (Garfin 2014, p. 470). Resulting increases in urban development, agriculture, and energy production facilities will likely place additional demands on already limited water resources. Climate change will likely increase water demand while at the same time shrink water supply, since water loss may increase evapotranspiration rates and run-off during storm events (Archer and Predick 2008, p. 25).

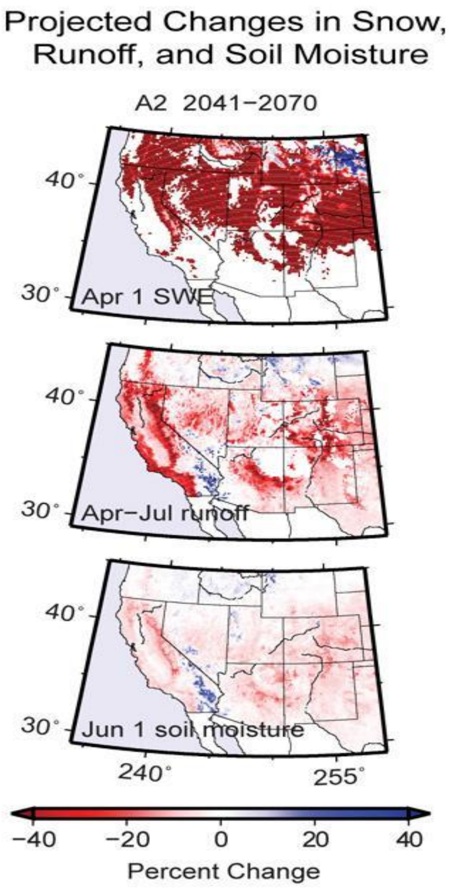


Figure 4.2. Mid-century (2041–2070) percent changes from the simulated historical median values from 1971–2000 for: (1) April 1 snow water equivalent (SWE, or snowpack, top), (2) April-July runoff (middle), and (3) June 1 soil moisture content (bottom), as obtained from the median of 16 Variable Infiltration Capacity (VIC) simulations under the high-emissions (A2) scenario (Garfin 2013, p. 118).

In order to identify changing climatic conditions more specific to sites where the nine springsnail species occur in Nevada and California, we conducted a climate analysis using the Climate Mapper web tool (Hegewisch et al. 2020, website) The Climate Mapper is a web tool for visualizing past and projected climate and hydrology of the contiguous United States of America. This tool maps real-time conditions, current forecasts, and future projections of climate information across the United States to assist with decisions related to agriculture, climate, fire conditions, and water.

Historical climate data comes from gridMET (AKA METDATA). The University of Idaho gridMET gridded surface meteorological dataset covers the continental US from 1979-present mapping surface weather variables at an approximate 4-km spatial grain. This dataset is updated by 12 pm daily with data for the previous day (i.e., 1-day lag) (Abatzoglou 2013, entire).

For projected climate data, projections from 20 climate models and 2 scenarios (RCP 4.5 and RCP 8.5) were downscaled to an approximate 4-km resolution across the U.S. for compatibility with the gridMET data (Abatzoglou and Brown 2012, entire).

For our analysis, we used the mapping tool to download geoTIFFs for the Mean Annual Temperature and percent precipitation using the historic period of 1971–2000 and the time period 2040–2069 as the future period for projection because models that go further into the future become less reliable. We then examined emission scenarios RCP 4.5 and RCP 8.5 using ArcGIS Pro.

Results from our analysis predict increased air temperatures where the springs in this SSA report occur (Fig. 4.3 and 4.4), whereas departures in precipitation are increasing (Fig. 4.5 and 4.6). Annual mean air temperature is projected to increase between 2.42 and 3.34°C (3.46 and 6.01 °F); average 2.88°C (5.18°F) throughout our action area between 2040 and 2069 (Fig. 4.3 and 4.4) (Hegewisch et al. 2020, GIS data). Projections related to annual precipitation range from percent increases of 4.92 to 7.44 percent among the two emission scenarios in Fig. 4.5 and 4.6 (Hegewisch et al. 2020, GIS data).

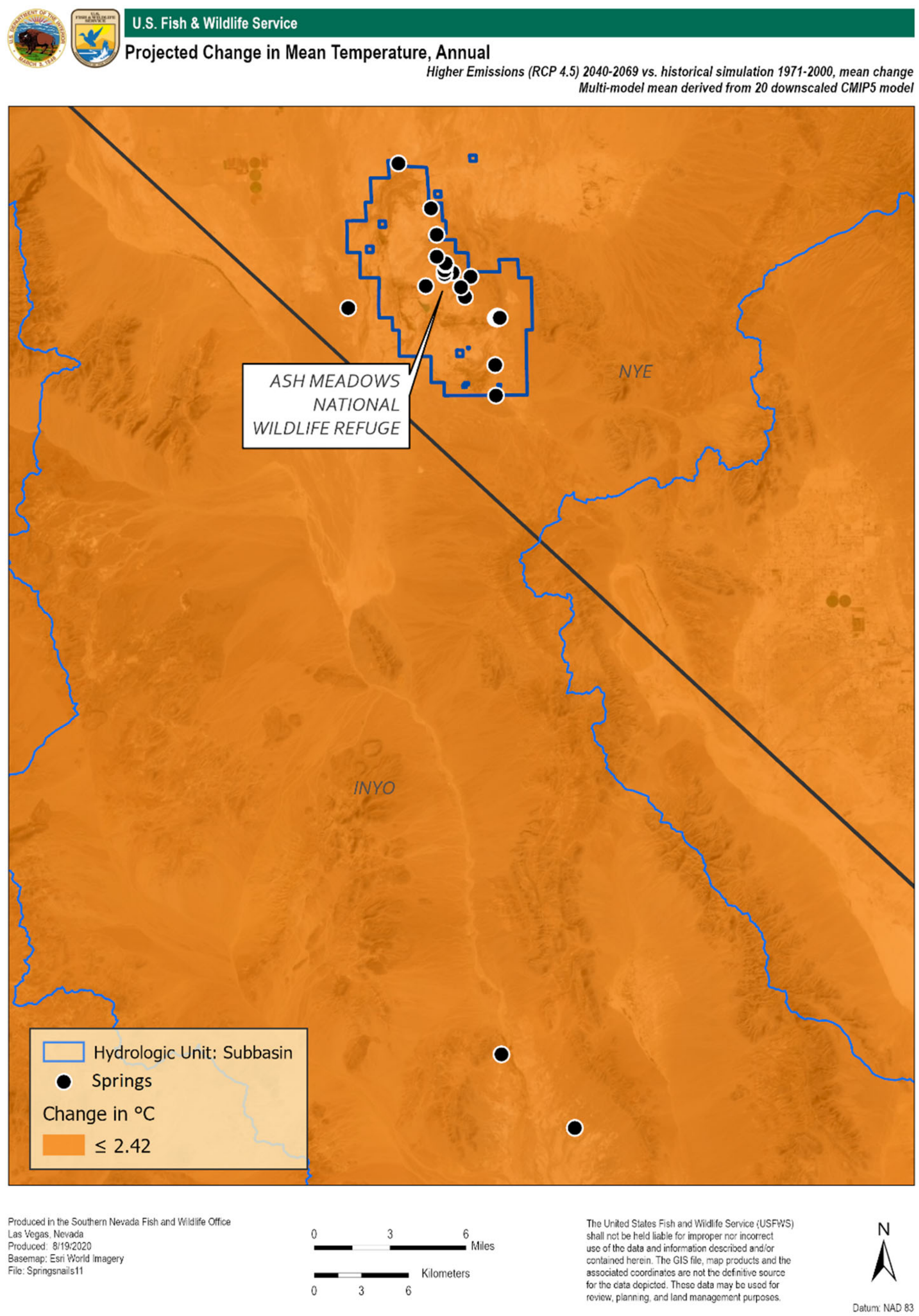


Figure 4.3. Map showing changes in average annual temperature predicted for the time period 2040–2069 as compared to the 1971–2000 baseline average using emission scenario RCP 4.5 (Hegewisch et al. 2020, website).

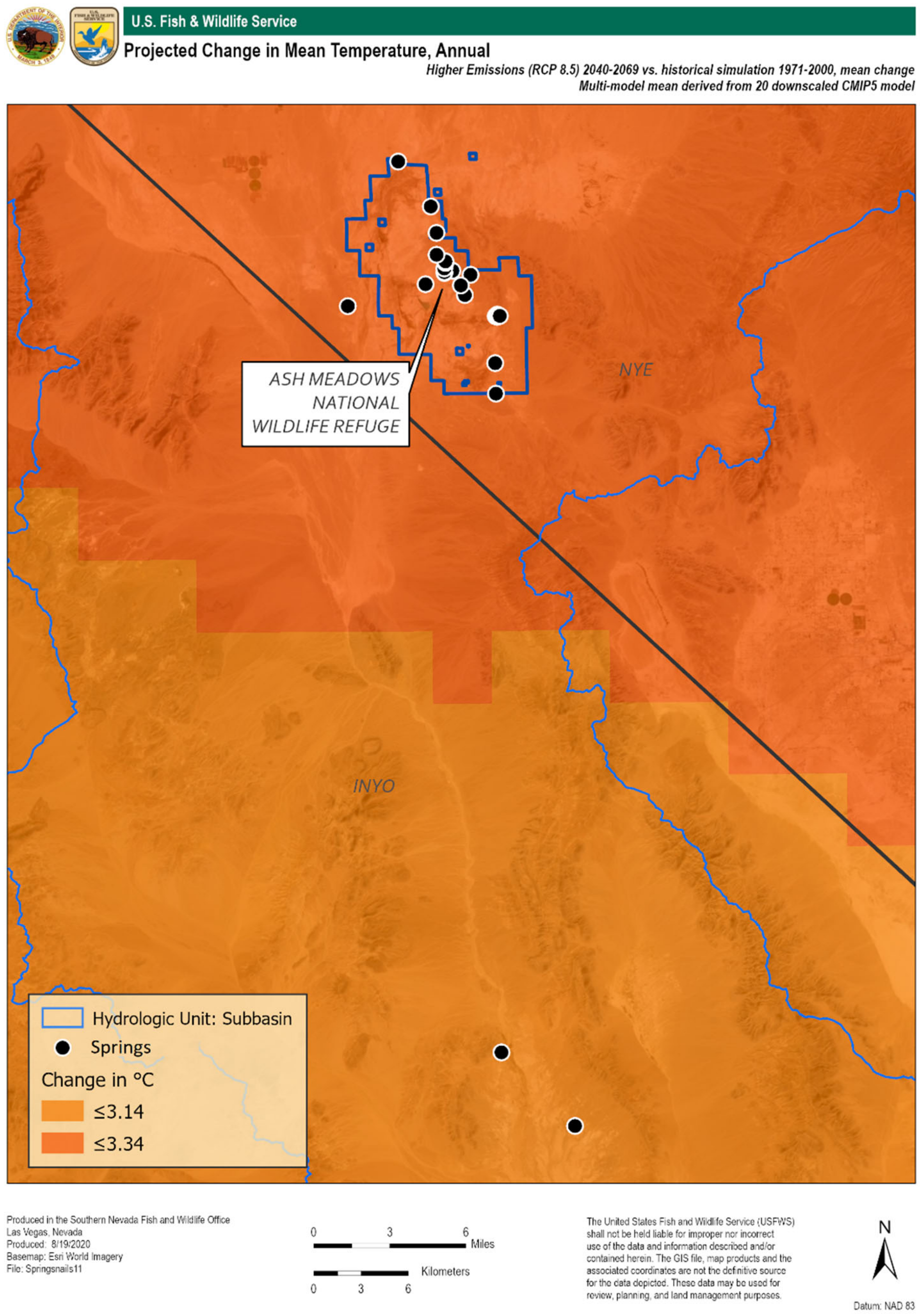


Figure 4.4. Map showing changes in average annual temperature predicted for the time period 2040–2069 as compared to the 1971–2000 baseline average using emission scenario RCP 8.5 (Hegewisch et al. 2020, website).

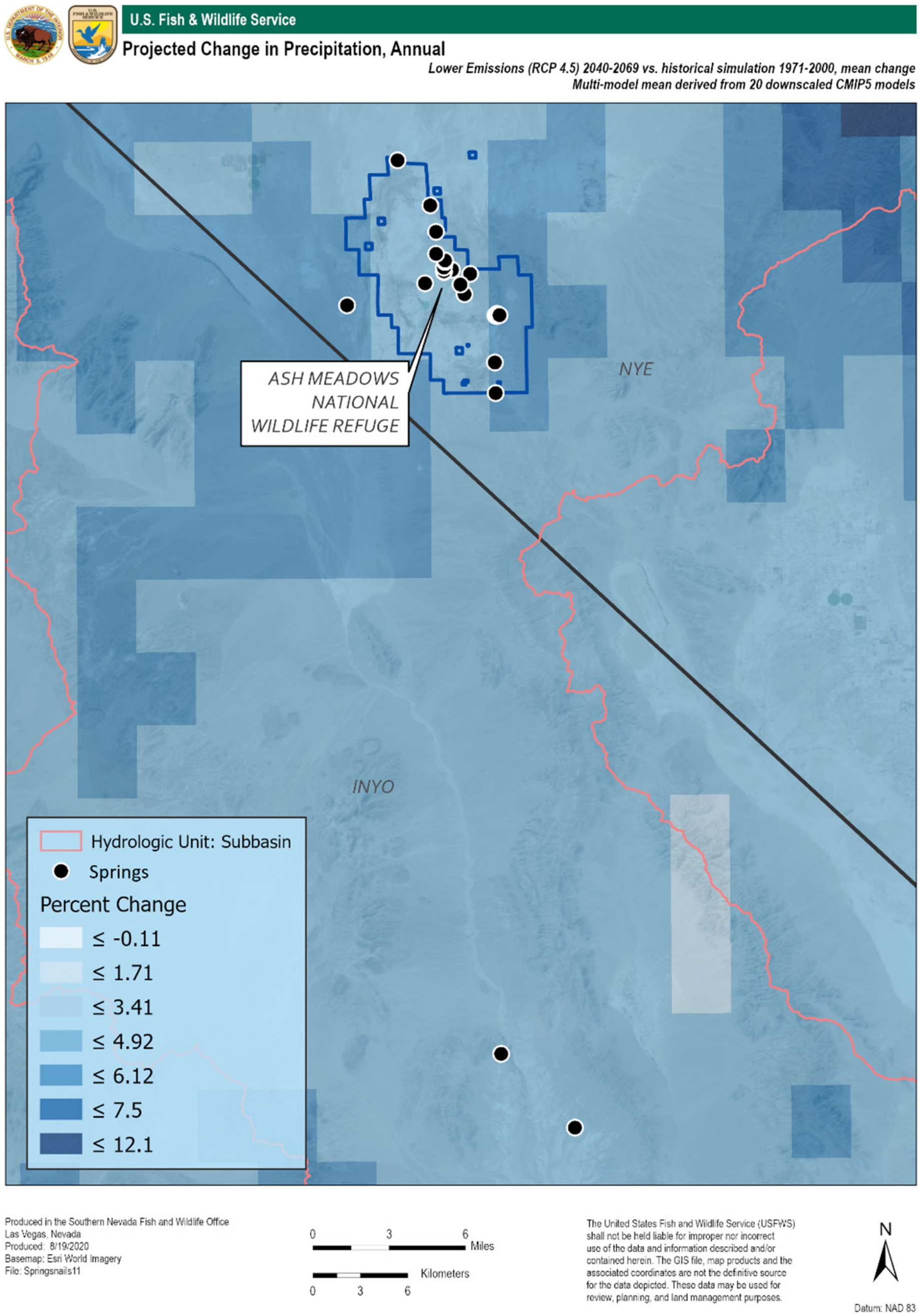


Figure 4.5. Map showing changes in average annual precipitation predicted for the time period 2040–2069 as compared to the 1971–2000 baseline average using emission scenario RCP 4.5 (Hegewisch et al. 2020, website).

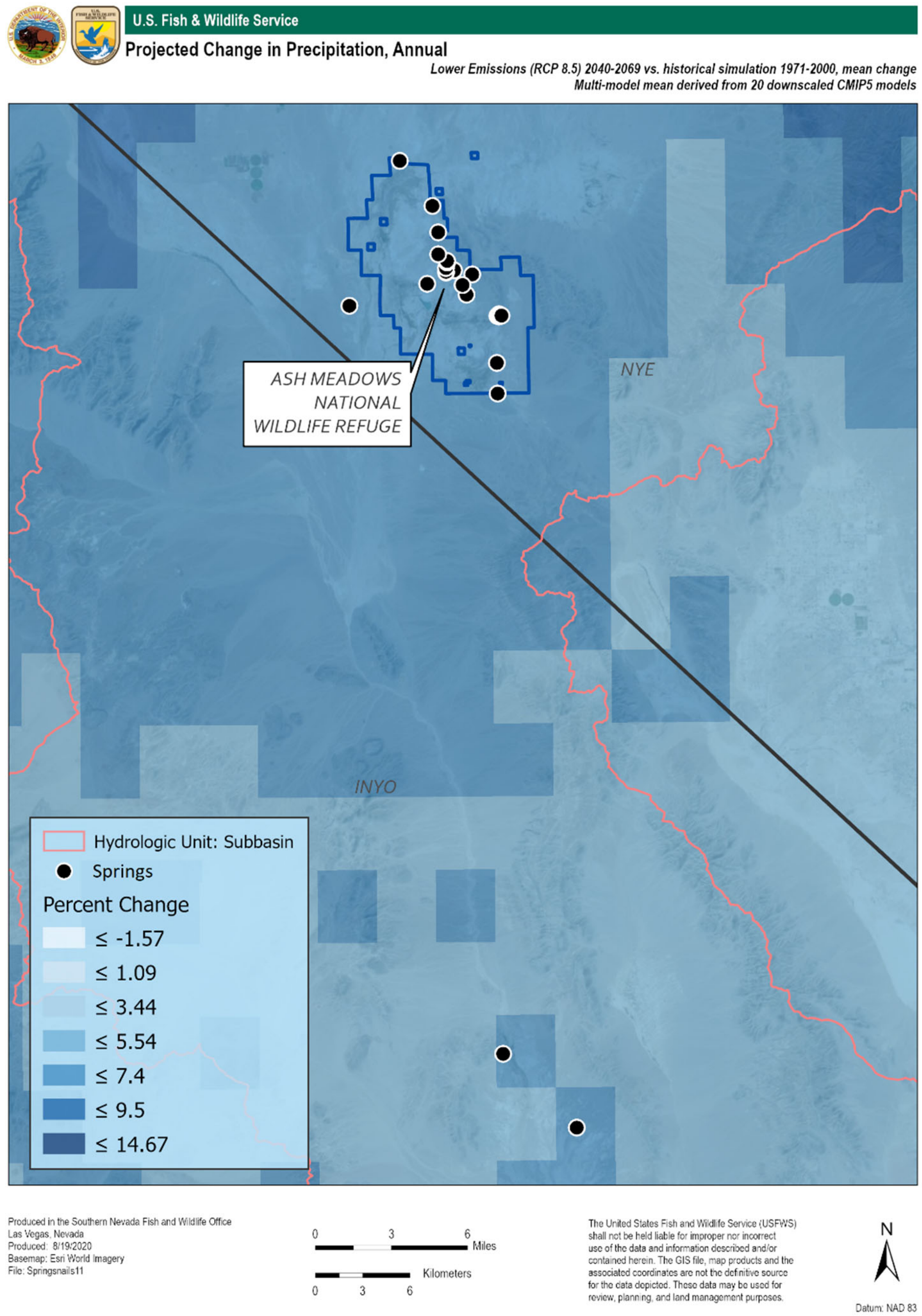


Figure 4.6. Map showing changes in average annual precipitation predicted for the time period 2040–2069 as compared to the 1971–2000 baseline average using emission scenario RCP 8.5 (Hegewisch et al. 2020, website).

Although it seems certain that climate change in conjunction with increased demands on water resources from a growing human population will result in lowered groundwater levels (Jaeger 2014, p. 13,895), little is known about how and when springflows may be affected by changes in climate. Direct hydrological connections have not been established in most cases, and for many areas, these connections remain difficult to make. The large number of springsnail species endemic to one or few locales speaks to the consistency and reliability of these aquatic habitats over millions of years. For example, although discharge and geographic extent of springs at Ash Meadows were higher 3 million years ago, Ash Meadows springs continue to discharge from the deep aquifer to this day (Deacon 2007, p. 690). Naturally occurring climatic variation results in changes in Ash Meadows groundwater levels, including a 9 m (29.5 ft) decline in groundwater 15,000 years ago as part of the drying trend that occurred at the end of the Pleistocene Epoch (Deacon 2007, p. 690). However, this prehistoric climatic decline is minor in comparison to documented historic cases in the nearby Las Vegas and Pahrump Valleys (Deacon 2007, p. 688). Groundwater level declines of up to 30 m (98 ft) in Pahrump Valley (Harrill 1986, p. 22) and up to 91 m (299 ft) in Las Vegas Valley (Burbey 1995, p. 9) were documented in 1975 and 1990, respectively. As a result of pumping events, several springs went dry in Pahrump Valley during the 1970s, including Manse springs, which led to extirpation of a local population of the Spring Mountains pyrg (*Pyrgulopsis deaconi*) in 1975 (Hershler 1998, p. 25). Examples such as this indicate that groundwater pumping, rather than climate change is a greater threat to springsnails.

Ultimately, the degree to which springflows are affected by climate change largely depends on influences on surface water processes and precipitation, since aquifers are recharged through exchanges with surface water (Green 2011, p. 541). Components of surface water systems that may be altered by climate change include atmospheric water vapor, precipitation patterns, rates of evapotranspiration, snow cover and melting of glaciers, soil temperature, and surface runoff and stream flows (Green 2011, p. 538). Changes to these components will likely result in changes to groundwater systems, but climate change impacts on groundwater resources are poorly understood (Green 2011, p. 533). Relationships between climate and groundwater are considered to be more complicated than those between climate and surface water (Holman 2006, p. 638). Interpretation of potential impacts is further complicated by a lack of data and background studies necessary to determine the magnitude and direction of possible groundwater changes (Kundzewicz 2008, p. 7). Furthermore, groundwater level responses are highly variable across a landscape due to spatial differences in sediment permeability and recharge characteristics. For example, increased precipitation often leads to higher groundwater levels at some testing locations but not at others nearby (Chen 2002, p. 106). Accordingly, some studies have shown a decrease in groundwater recharge rate, while others have predicted positive effects or concluded that it is not known whether overall groundwater recharge will increase, decrease, or stay the same throughout the western U.S. as a result of climate change (Jyrkama and Sykes 2007, p. 248; Herrera-Pantoja and Hiscock 2008, p. 12; Gurdak and Roe 2010, pp. 1,762–1,763).

Climate change may impact springsnails and their habitats in two main ways: (1) Reductions in springflow as a result of changes in the amount, type, and timing of precipitation, increased evapotranspiration rates, and reduced aquifer recharge; and (2) reductions in springflow as a result of changes in human behavior in response to climate change (e.g., increased groundwater pumping as surface water resources disappear). Impacts vary geographically, but identifying which springs may be more or less vulnerable is challenging. For example, a study examining different short-flowpath springs over a 14-year period at Arches National Park found that each spring responded to local precipitation and recharge differently, despite similarities in topographic setting, aquifer type, and climate exposure (Weissinger et al. 2016, p. 9).

Regional springs (Chapter 3.2) are typically fed by older and larger aquifers compared to mountain block aquifers, and have relatively longer residence times (sometimes hundreds to thousands of years for regional aquifers) (Sada 2017, p. 4). Local and regional springs also tend to occur in low elevation alluvial fans and valley floors where production wells are typically located. In this case, effects to these aquifers may be more driven by increased groundwater extraction rather than climate-driven decreases in recharge.

Predicting individual spring response to climate change is further complicated by the information available explaining the large-scale hydrological connections for most sites and the high degree of uncertainty inherent in future precipitation models. Regardless, the best available data indicates that all springsnail sites in the analysis area may be vulnerable to drier climate change conditions.

4.4 Land Management and Conservation Plans

A variety of regulatory and voluntary conservation measures are currently in place to help reduce the potential negative impacts from some of the potential threats. Many threats are mostly historical or have stabilized over time, and have little effect on springsnail species needs. However, there are also ongoing threats with substantial negative effects (e.g., old spring diversions, predation, competition), and future threats (e.g., increased groundwater pumping/altered precipitation and temperature) on which conservation planning can help reduce. While we cannot definitively know to what extent these future threats may impact springs or spring provinces, there are land management and conservation plans in place on various lands that should provide protections for some springsnail species and their needs. These include laws, regulations, policies, and management plans on Federal lands, state plans in Nevada, and ongoing efforts to work with private landowners when possible. Plans may include specific conservation actions for springsnail species and protecting species needs, while others may include more broad protections for aquatic and riparian species habitat or protections from future water withdrawals. Such protections provide some assurances that current individual-level threat impacts will not become population-level impacts and that potential future threats will not occur or impact springsnail species needs. These measures are outlined in numerous land management and conservation plans listed in Appendix A.

4.5 Summary

Current threats and their impacts differ by spring and spring province, and are variously influenced by a combination of contemporary and legacy events in the history of the spring. In some instances, historical threats have been partially or fully mitigated (e.g., historical dredging with recovered riparian vegetation), whereas at other locations historical events fully continue to impact the species or habitat at present (e.g., impoundment, peat mining, invasive species, recreation). For many springs on the Ash Meadows NWR today, the relative influence of historical and current threats have shifted over time as the Service has protected and improved some habitats. Specific conservation measures are in place to determine springsnail viability and vulnerability to extinction, and to prioritize recovery actions. In general, current threats include predation and competition from invasive aquatic species, vegetation and soil disturbance, recreation, spring manipulation, and various legacy effects. In addition to the above, the most significant threat is reduced spring discharge resulting from groundwater pumping in the region. Specific threats for the conservation each habitat and species is presented in the following Chapters (5.1 and 5.2, respectively).

5.0 CURRENT CONDITIONS—SPRINGSNAIL HABITATS AND SPECIES VIABILITY

In this chapter, we provide current information on springsnail populations pertinent to the nine species considered in this report. This information is organized by habitat, and includes the historical and current distribution of springsnail species, the relative abundance of species where information is available, and the current condition of each spring habitat. Current condition of habitat is classified into four levels relative to springsnails: high, moderate, low, or dry. The next chapter (5.2) summaries the current condition of each species. The current species viability is inferred here using the collective information of the individual habitats in which they occur. Note that the current condition of each species are evaluated and reiterated as future *Scenario 1* in the following chapter, given that this future scenario assumes conditions remain similar to current viability.

5.1 Amargosa Desert Hydrographic Area (230) – Springs and Spring Provinces and Current Habitat Condition

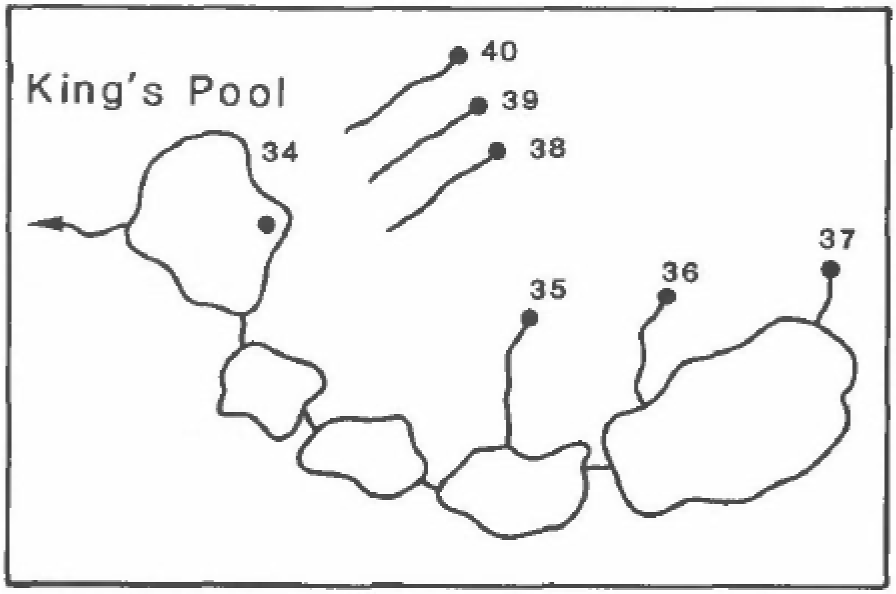
5.1.1 Kings Pool (Ash Meadows NWR)

Kings Pool and its outflow represent one of the major, large spring pools and outflows (approximately 4542 L/min (1,200 g/min); Dudley and Larson 1976, p. 36) at the Ash Meadows NWR (Fig. 2.1), with a long stretch of springsnail-occupied habitat extending downstream [370 m (1,214 ft)] and of considerable depth [average 46 cm (18 in); USGS 2018, entire]. This large site is situated near several smaller peripheral spring outflows that are treated separately below (Point of Rocks spring province) given the vast differences in habitat size, and the historical distinctiveness of Kings Pool from the nearby smaller springs. Kings Pool and its outflow support two species of springsnails considered in this SSA report, both of which occurred here historically and currently, and vary in abundance with respect to recent surveys (Appendix B.1a). The first species, Amargosa tryonia, is distributed in the Kings Pool outflow and among several other springs across the Refuge. The second species, the Ash Meadows pebblesnail, is restricted to this single location as originally described by Pilsbry in 1899 (see Hershler and Sada 1987, entire). Threats for the habitat at Kings Pool are minimal, and include disturbance due to recreational visitors to the Refuge. The Kings Pool is one of many restored habitats at the Refuge, and the site is maintained for visitors by restricted access via a boardwalk. The spring is best characterized as protected, restored, naturalized to stable conditions, and is in overall high condition.

5.1.2 Point of Rocks Spring Province (Ash Meadows NWR)

The Point of Rocks Spring Province is an area that consists of multiple clustered small- to moderate-size rheocrene springs in the Ash Meadows NWR (Fig. 2.1, Fig. 5.1). These springs and their springsnail taxa, which are closely associated with the large Kings Pool described above, are described in Hershler and Sada (1987, p. 786). The small to moderate size springs in this complex are referred to as unnamed #35, #36, and #37, with smaller seeps labelled #38, #39, and #40 (Fig. 5.1.2). Springs vary in size from < 1 L/m (<0.001 cfs) to 100 L/m (0.06 cfs) (USGS 2018, entire). Collectively, these six outflows currently support two Point of Rocks endemic springsnails: the Ash Meadows pebblesnail and the Point of Rocks tryonia (Appendix B.2a). Additionally, a third springsnail, the widespread Amargosa tryonia—historically occurred at two of the small outflows. Across the spring province, *Pyrgulopsis* is more abundant here today than *Tryonia*. Part of the reason *Pyrgulopsis* may be more abundant is that more of the springhead habitat (well suited to *Pyrgulopsis*) was restored relative to the finer substrate approximately 2 to 4 m (6 to 13 ft) downstream. Similar to Kings Pool, threats are minimal from disturbance due to recreational visitors. However, the small seeps (#38, #39, #40) are sufficiently small that water and springsnails are not always encountered on every survey (USGS 2018, entire; Service 2020, entire), and are susceptible to natural variation in discharge that result in near-dry conditions during drought. Overall, the habitat is characterized as protected, restored, appears stable, and in moderate condition.

Figure 5.1.2. Diagram of the Point of Rocks spring province. (Figure reproduced unmodified from Hershler and Sada 1987, p. 785). Numbers referred to spring outflows referenced herein.



5.1.3 Big Spring (Ash Meadows NWR)

Big Spring is one of the four largest spring pools and outflows at the Ash Meadows NWR (Fig. 2.1). Discharge at this limnocrene is approximately 3940 L/min (1,041 g/min) (Hershler and Sada 1987, p. 843). This spring and outflow support one springsnail, the sportinggoods tryonia. This species was described here historically and is present today (Appendix B.3a). The Sportinggoods tryonia is scarce by relative abundance in the long outflow of 548 m (1795 ft), but occurs with common abundance within the first 165 m (540 ft) downstream from the source (USGS 2018, entire). The spring is impacted by water division that occurs approximately 152 m (500 ft) downstream of the spring source. Additional threats include various predator threats from fishes introduced to the spring system, as well as crayfish. This spring is one of the habitats outlined by the Desert NWR Complex Natural Resource Management Plan for renovation to remove aquatic predators and improve the site (Appendix A). Overall the site is in moderate condition.

5.1.4 Chalk Spring (Ash Meadows NWR)

Chalk spring is located in the north-central part of the Ash Meadows NWR (Fig. 2.1). Historically, the spring was described with discharge less than 10 L/min (2.6 g/min) with an outflow less than 100 m (328 ft) long (Hershler and Sada 1987, p. 840). This small rhoecrene spring historically supported two species of springsnails, one of which—the Amargosa tryonia—is considered in this SSA report. This species is widespread across Ash Meadows and occurs in at least 12 other springs. The habitat is remote, not regularly visited by Refuge staff or visitors, nor routinely surveyed. The site was most recently surveyed in 2018 and was found to be dry (USGS 2018, entire). Vegetation was observed at the source of the spring, but no open water was found. It is unknown why this spring was dry, and could be the result of several factors, potentially including groundwater pumping, drought, changes in vegetation, or some combination of those factors. Specific threats for this habitat are unknown, and future surveys are needed to determine if surface water has returned, or remains dry. Overall, the current condition of the spring is characterized as dry.

5.1.5 Collins Ranch Spring (Ash Meadows NWR)

Collins Ranch Spring is a small, diffuse rheocrene spring located in the central part of the Ash Meadows NWR (Fig. 2.1). Historically, the spring was described with discharge approximately 40 L/min (11 g/min) with an outflow of roughly 75 m (246 ft) long (Hershler and Sada 1987, p. 841). This small rhoecrene spring supports two species of springsnails, both of which are considered in this SSA report: The distal-gland springsnail and the widespread Amargosa tryonia. Although spring discharge is low relative to other springs, it supports what appears to be a healthy population (both historically and currently) of both *Pyrgulopsis* and *Tryonia*). The small volume of water discharged from this spring makes is vulnerable to changes in hydrology (Service 2020, entire). Note that during the USGS 2018 survey that significant native vegetation was observed at the source of the spring, and no open water was found (USGS 2018, entire). However, the site has since undergone a prescribed burn to improve habitat conditions, and both species were recorded as common (Service 2020, entire). Threats include slight disturbance from recreation and general susceptibility to fluctuations of spring discharge. The current condition of this spring is best characterized as high/moderate.

5.1.6 North of Collins Ranch Springs (Ash Meadows NWR)

The North of Collins Ranch springs consist of at least two small seeps located in the central part of the Ash Meadows NWR (Fig. 2.1). These small seeps are difficult to identify because the surface water is not readily apparent. Three springsnail species occurred historically at these seeps (Hershler and Sada 1987, entire) —the Minute tryonia, Amargosa tryonia, and the distal-gland springsnail. The distal-gland springsnail is historically recorded from the North of Collins Ranch Spring, as well as the nearby Collins Ranch Spring, while the Minute tryonia only additionally occurs in North Scruggs Spring. The third species, the Amargosa tryonia, is widespread across Ash Meadows. These seeps are not regularly visited by visitors or refuge staff, nor are they routinely surveyed. Surveys for this report in 2018 (USGS 2018, entire) were unable to locate wetted habitats. A subsequent survey in 2020 located these seeps and found with little water present, and no springsnails were observed at these sites (Service 2020, entire). We are uncertain why these seeps are drying and characterized by inadequate discharge in 2020, although it could be the result of several interacting factors, including groundwater pumping, drought, changes in vegetation, or some combination of those factors. At this time, specific threats are unknown other that natural fluctuations in discharge. Further surveys that incorporate seasonal variation and extensive sampling are required. Overall, the current condition of these springs are characterized as low.

5.1.7 Crystal Spring (Ash Meadows NWR)

Crystal Spring is largest spring at Ash Meadows NWR (Fig. 2.1), located immediately south of the visitor center and Refuge headquarters. The spring discharges over 31.5 L/sec (500 g/min) and supports the longest springbrook habitat at Ash Meadows, ending in a marsh and reservoir approximately 2 km (~1.2 mi) downstream. This large spring supports two species of springsnails with vastly different distributions. The spring pool orifice supports an exceedingly rare single-site endemic, the Crystal springsnail, which inhabits only the first meter (~3 ft) around the spring orifice. The species was described (Hershler and Sada 1987, p. 747) as occurring within habitat size of 1 m^2 (11 ft^2). The long springbrook extending from the spring supports the Sportinggoods tryonia for more than 275 m (900 ft) downstream (USGS 2018, entire); this species also occurs in other springs throughout Ash Meadows NWR. Historical distribution and abundance of both species has not changed since the species was first described (Hershler and Sada 1897, entire), with the Crystal springsnail considered scarce, and the Sportinggoods tryonia known to be abundant. The high discharge (and to a lesser extent other large springs like Fairbanks, Big and Kings Pool) may have permitted the exceedingly rare *Pyrgulopsis* to survive over thousands of years. Threats to this spring include invasive fishes, crayfish, and red-rimmed melania. Overall, the current condition of this spring is best characterized as moderate.

5.1.8 Fairbanks Springs (Ash Meadows NWR)

Fairbanks Spring is a large limnocrene located in the northern part of the Ash Meadows NWR (Fig. 2.1). Discharge is approximately 6,500 L/min (1,717 g/min). The spring has a long outflow that provides more than 400 m (1,312 ft) of springsnail habitat that joins outflows of several other springs in Carson Slough drainage of the Refuge (Rodgers, Five Springs, Soda, and Longstreet springs). Similar to Crystal Spring (above), this large spring also supports two species of springsnails; the single-site endemic Fairbanks springsnail occurs near the source pool and the long springbrook supports the Sportinggoods tryonia for more than 400 m (1,312 ft) downstream (USGS 2018, entire). The Sportinggoods tryonia also occurs in two other springs at Ash Meadows NWR. The spring pool has been historically enlarged and modified prior to the Refuge ownership, and restored during Refuge ownership in 2010 (Service 2002, Appendix C). The current condition of the habitat is stable and has become naturalized over time; however, the area surrounding the spring has sustained slight disturbance (i.e., pedestrian foot traffic) from public visitors. Significant threats include nonnative fish predators (mosquitofish), invasive snails (red-rimmed melania), and residual impacts from historically installed water diversions. As with Crystal above, the large discharge of this spring likely affords secure conditions for springsnails to survive despite ongoing threats. Overall, the current condition of this spring is best characterized as moderate.

5.1.9 Five Springs Province (Ash Meadows NWR)

The Five Springs province is a series of small- to moderate-sized springs located in the north-central part of Ash Meadows NWR (Fig. 2.1). The outflows exhibit varying levels of discharge, but all less than 1 L/min (0.26 g/min) (USGS 2018, entire). The springbrooks emanating from the springs collectively converge and flow west 3 km (1.9 mi) toward Carson Slough, a major north-south drainage on the east side of the Refuge. Prior to Refuge stewardship, the outflows where channelized into earthen canals by heavy machinery, and springsnails were restricted to a small area where the outflows combined, but not below a barrier that separated them from invasive red-rimmed melania (Hershler and Sada 1987, p. 840). This province supports three species of springsnails. However, the distal-gland springsnail and the widespread Amargosa tryonia, are considered in this SSA report. Both species occurred here historically and their abundance at present is considered common (USGS 2018, entire). The Ash Meadows NWR restored the spring habitat in 2016 (Appendix B.9a) and appears stable today. Ongoing threats include aquatic invasive snails (red-rimmed melania). Overall, the current condition of the spring province is best characterized as moderate.

5.1.10 Last Chance Spring (Ash Meadows NWR)

Last Chance Spring is a small seep that originates from a heavily vegetated area on the south end of the Ash Meadows NWR (Fig. 2.1). Flow was reported as less than 10 L/min (2.6 gal/min) and flowed for only 5 m (16 ft) before entering a dense vegetation in 1987 (Hershler and Sada 1987, p. 843). Recent surveys in 2018 (USGS, entire) were unable to find surface water. However, resurvey in 2020 reported extremely low flow conditions, but a wetted area extending west from the dry spring box for more than 50 m (164 ft) (Service 2020, entire). This spring has historically supported two species of springsnails, although only one, the widespread Amargosa tryonia, is considered in this SSA report. Although Amargosa tryonia has occurred here historically, it has not been found during the last three surveys (Appendix B.10a). The primary threats at this spring is excessive vegetation choking the spring source (i.e., cattails), where little open water currently remains. Additionally, there is evidence of native herbivores using the seep, and surface disturbance from trampling is evident. Overall, the current condition of the spring is best characterized as low.

5.1.11 South of Clay Pits Spring (Private)

The South of Clay Pits Spring occurs adjacent to and immediately west of the Ash Meadows NWR (Fig. 2.1). This spring is one of few springs in the Ash Meadows area that occurs on private land. This spring is known historically to support several species of springsnails; the *Amargosa tryonia*, as well as two other species not considered in this report occur here, the elongate-gland springsnail (*Pyrgulopsis isolatus*) and the curved filament pyrg (*Pyrgulopsis* *licina*). At the time of the Amargosa tryonia's taxonomic description from this spring (i.e., 1987), the habitat was characterized with flow extending from a large, potentially modified pit for 100 m (328 ft), where springflow ended in wetland habitat (Hershler and Sada 1987, p. 842). More recently, surveys document the area as highly manipulated by heavy machinery (USGS 2018, entire), and no springsnails were found of any species. Additionally, evidence of recreation (e.g., beer bottles, fireworks) and a recent fire were apparent in the spring area. Unlike the protected Refuge lands, the best available information suggests this area has significant impacts beyond that described in 1987 (Hershler and Sada 1987, p. 842), which report a seemingly natural character with some evidence of grazing. In 2018, only stagnant water with algae was present near the end of the pool, and the total pool and spring habitat was approximately 100 m (328 ft) in length. At this time, further surveys are required at this location to determine if the spring is no longer suitable for springsnails. Ongoing discussions with the landowner are planned to resurvey the site thoroughly, and across several seasons, before determining if this species is still present and viable.

5.1.12 Marsh Spring (Ash Meadows NWR)

Marsh Spring is one of several geographically proximate springs that occur in the central portion of the Ash Meadows NWR (Fig. 2.1), an area known as Warm Springs. The Warm Springs area corresponds to the range of Warm Springs pupfish (*Cyprinodon nevadensis pectoralis*), a unique species closely related to the Ash Meadows Amargosa pupfish (*Cyprinodon nevadensis mionectes*). Discharge at Marsh Spring is estimated at 600 L/min (158.5 gal/min). When initially described, Marsh Spring was impoundment by a small dike 30 m (98 ft) below the source causing surface flow to disperse (since removed by the Service). The spring supports two species of springsnails (Hershler and Sada 1987, p. 841), both of which are addressed in this report: the median-gland springsnail and the Amargosa tryonia. The median-gland springsnail is endemic to several springs in the Warm Springs Area, while Amargosa tryonia is widespread across the Refuge. Both species that occurred here historically are present at the most recent surveys (USGS 2018, entire; Service 2020, entire). However, like most springs in the Warm Springs area, flow is small relative to the large springs at Ash Meadows NWR (e.g., Crystal, Big and Fairbanks springs and Kings Pool). The Warm Springs area is some of the best restored and protected habitat on the Refuge, and shows no significant disturbance, and low levels of aquatic predators (USGS 2018, entire). Overall, the current condition of the spring is best characterized as moderate.
.

5.1.13 Mary Scott Spring (Ash Meadows NWR)

Mary Scott Spring is a small rheocrene spring located centrally within the Ash Meadows NWR (Fig. 2.1). Discharge at Mary Scott Spring is small (estimated at 600 L/min (158.5 gal/min)), emerges from a pool less than 1 m (3.2 ft) wide, and described to support two species of springsnails (Hershler and Sada 1987, p. 840), the distal-gland springsnail and the Amargosa tryonia. The distal-gland springsnail occurs in at least two other springs in the central part of As Meadows NWR, while the Amargosa tryonia is widespread across the Refuge, occurring in at least 11 other springs or spring provinces. Both species occurred here historically and are currently common in abundance (USGS 2018, entire; Service 2020, entire). The flow at this spring is small relative to the larger springs at Ash Meadows springs (e.g., Crystal, Big, Fairbanks, and Kings Pool). The channel was modified historically by impoundment (Hershler and Sada 1987, p. 840) and it flows to a marsh that is more than 250 m (820 ft) downstream (USGS 2018, entire). The site is characterized by some disturbance resulting from herbivore trampling around the spring source. Overall, the current condition of the spring is best characterized as moderate.

5.1.14 North Indian Spring (Ash Meadows NWR)

North Indian Spring is one of several geographically proximate springs that occur in the centrally located Warm Springs area of Ash Meadows NWR (Fig. 2.1), and approximately 150 m (492 ft) north of South Indian Spring (Section 5.1.15, below). Discharge at North Indian Spring is estimated at 400 L/min (106 gal/min)); it has a small spring pool less than 1 m (3.3 ft) wide. The outflow of both North and South Indian Springs converge after several hundred meters (~600 ft), and contribute to flow extending downstream approximately 700 m (2,297 ft). One springsnail species is known to occur here both historically (Hershler and Sada 1897, p. 841) and currently: Amargosa tryonia. The most recent surveys in 2018 and 2020 document that the species is scarce in abundance (USGS 2018, entire; Service 2020, entire). Like most springs in the Warm Springs area, flow is small relative to the larger springs at Ash Meadows NWR (e.g., Crystal, Big, Fairbanks, Kings Pool), and thus potentially more susceptible to changes in hydrography. The habitat around the Warm Springs area was modified historically, but has been stable (including the North Indian Spring) as part of the Refuge. Currently, the habitat at North Indian Spring is slightly impacted by heavy vegetation and aquatic competitors and predators (red-rimmed melania) in some areas (USGS 2018, entire). Overall, the current condition of the spring is best characterized as moderate.

5.1.15 South Indian Spring (Ash Meadows NWR)

South Indian Spring is one of several geographically proximate springs that occur in the centrally located Warm Springs area of Ash Meadows NWR (Fig. 2.1); it is approximately 150 m (492 ft) south of North Indian Spring (Section 5.1.14, above). Discharge at South Indian Spring is estimated at 200 L/min (53 gal/min), approximately half of North Indian Spring. This small rheocrene spring supports a narrow channel extending into an ash and mesquite grove (Hershler and Sada 1897, p. 841). Similar to North Indian Spring, this spring historically supported one species of springsnail: Amargosa tryonia. Recent surveys document the species is common in abundance (USGS 2108, entire; Service 2020, entire). Like most springs in the Warm Springs area, flow is small relative to the larger springs at Ash Meadows NWR (e.g., Crystal, Big, Fairbanks, Kings Pool), and thus potentially more susceptible to changes in hydrography. The habitat around the Warm Springs area, and South Indian Spring in particular, has been restored, and is protected from public access. This spring is in high condition, in spite of the presence of predatory, nonnative red-rimmed melania in some areas (USGS 2018).

5.1.16 North Scruggs Spring (Ash Meadows NWR)

North Scruggs Spring is one of several geographically proximate small springs that occur in the centrally located Warm Springs area of Ash Meadows NWR (Fig. 2.1), and approximately 30 m (98 ft) north of South Scruggs Spring (Section 5.1.17, below). Discharge at North Scruggs Spring is approximately 227 L/min (60 gal/min) when described by Hershler and Sada (1987, p. 840). The flow includes an engineered channel that converges with the flow of South Scruggs Spring and extends approximately 2 km (~1.2 mi) to the west. Three species of springsnails (all addressed in this report) historically (Hershler and Sada 1897, p. 841) and currently occur at this spring: the median-gland springsnail, the minute tryonia, and the Ash Meadows-wide Amargosa tryonia. The median-gland springsnail is a narrow endemic (Warms Springs area) restricted to North Scruggs, Marsh, and School springs (see also Sections 5.1.12 and 5.1.18). The minute tryonia is also highly restricted, occurring only in this spring and the minor seep North of Collins Ranch Spring (potentially extirpated, Section 5.1.6). Based on recent surveys with respect to relative abundance of live springsnails, the median-gland spring is considered common and the other two (*Tryonia*) are common (2018) or scarce (2020) (Appendix B.16a; USGS 2018, entire; Service 2020, entire). Like most springs in the Warm Springs area, flow is small relative to larger springs at Ash Meadows NWR (e.g., Crystal, Big, Fairbanks, Kings Pool), and thus potentially more susceptible to changes in hydrography. The habitat around the Warm Springs area, including North Scruggs Spring, was modified historically, but has been stabilized as part of stream restorations by the Refuge. The habitat at this spring is slightly impacted by heavy vegetation and aquatic competitors and predators (red-rimmed melania) in some areas (USGS 2018, entire). Overall, the current condition of the spring is best characterized as moderate.

5.1.17 South Scruggs Spring (Ash Meadows NWR)

South Scruggs Spring is one of several geographically proximate small springs that occur in the centrally located Warm Springs area of Ash Meadows NWR (Fig. 2.1a), and it is approximately 30 m (98 ft) south of North Scruggs Spring. Discharge at South Scruggs Spring is approximately 230 L/min (61 gal/min), with flow joining that of North Scruggs Spring and extending approximately 2 km (~1.2 mi) to the west. One springsnail species has historically (Hershler and Sada 1987, p. 841) and continues to occupy this spring: the widespread (Ash Meadows-wide) Amargosa tryonia. Like most springs in the Warm Springs area, flow is small relative to larger springs at Ash Meadows NWR (e.g., Crystal, Big, Fairbanks, Kings Pool), and thus potentially more susceptible to changes in hydrography. Similar to North Scruggs Spring, habitat around the Warm Springs area, including South Scruggs Spring, was modified historically, but has been stabilized as part of stream restorations by the Refuge. The habitat at present is slightly impacted by invasive aquatic competitors and predators (red-rimmed melania) in some areas, although springsnails are abundant (USGS 2018, entire). Overall, the current condition of the spring is best characterized as moderate.

5.1.18 School Spring (Ash Meadows NWR)

School Spring is small rheocrene spring centrally located in the Warm Springs area of Ash Meadows NWR (Fig. 2.1). Discharge at School Spring is approximately 75 L/min (20 gal/min), with an outflow extending approximately 700 m (2,297 ft) as historically described in Hershler and Sada (1987, p. 841). Two species of springsnails (within this SSA) historically and currently occur here: the median-gland springsnail and the widespread (Ash Meadows-wide) Amargosa tryonia. The median-gland springsnail is a narrow endemic restricted to School Spring, North Scruggs Spring, and Marsh Spring (see Sections 5.1.12, 5.1.16). Recent surveys indicate that both species are common or abundant at this spring (Appendix B.16a). Like most springs in the Warm Springs area, flow is small relative to larger springs at Ash Meadows NWR (e.g., Crystal, Big, Fairbanks, Kings Pool), and thus potentially more susceptible to changes in hydrography. The habitat around the Warm Springs area, including the School Spring, was modified historically, but has been stabilized as part of stream restorations by the Refuge. Overall, the current condition of the spring is best characterized as moderate.

5.1.19 Near Crystal Reservoir (Ash Meadows NWR)

Two unnamed spring outflows were described by Hershler and Sada (1987, p. 842) near Crystal Reservoir. These outflows emerged from well casings atop a spring mound, and merged to form a 2 m (6.5 ft) outflow, that together to form a large wetland. The outflows historically supported two species of springsnail, one of which, the Amargosa tryonia, is considered in this report. Sada revisited the spring in 2008 (Sada 2008, unpublished information) and found all species of springsnails scarce in abundance. The spring habitats were visited specifically for this report in 2018 and surveyors found no surface water (USGS 2018, entire). Only dense terrestrial vegetation remains, and no water or springsnails were recorded (Appendix B.19a). It is unknown why the spring is currently dry, and if other threats for springsnails occur at the site. Overall, the current condition of the spring habitat is best characterized as dry.

5.1.20 Devils Hole (Death Valley National Park)

Devils Hole is a pool formed by a collapsed limestone cavern at elevation of 741 m (2,431 ft). This 68 m^2 (732 ft^2) pool has no outflow, and the water level is 15 m (49 ft) below the land surface. Only one springsnail, the Amargosa tryonia, has occurred here historically (Hershler and Sada 1987, p. 841) and is present today (Devils Hole Incident Command Team 2020, pers. comm.). The spring is managed under the jurisdiction of Death Valley National Park, but located within the boundaries of Ash Meadows NWR. The pool is intensively monitored by National Park Service (NPS) staff and the Incident Command Team (an interagency group comprised of the NPS, Nevada Department of Wildlife, and the Service), via monthly meetings and recovery actions, to manage the endangered Devils Hole pupfish and the habitat. Although the pool was not surveyed specifically for springsnails by the Service, the NPS *Long-Term Ecological*

Monitoring Program conducts springsnail surveys monthly. The NPS has documented that this springsnail species is abundant at present, and has been since the beginning of this monitoring program in 2008 (K. Wilson 2020, *unpubl.*). Here, Amargosa tryonia occurs in Devils Hole at exceptional frequency relative to habitats elsewhere. The habitat of Devils Hole is fenced by a locked gate, and is managed, restored, and protected; however, it has recently been susceptible to vandalism (https://www.nationalparkstraveler.org/2018/10/third-nevada-man-sentenced-vandalism-devils-hole). Increased security makes Devils Hole the most secure habitat in the Ash Meadows area. At present there are no threats to the Amargosa tryonia at Devils Hole; therefore, the current condition of the spring is characterized as high.

5.1.21 Shoshone Spring (Shoshone, CA)

Shoshone Spring is located in the town of Shoshone (Inyo County, California), and supports several species of springsnails, including the Amargosa tryonia, when originally described by Hershler and Sada (1987, entire). The spring occurs on private land, and has been recently renovated with assistance from state and federal agencies. Although few springsnail surveys have been conducted here, the spring was renovated in 2015 to support the endemic Shoshone pupfish (*Cyprinodon nevadensis shoshone*) (Moyle et al. 2015, p. 4). During the renovation in 2015, springsnails where identified to genus, and only *Pyrgulopsis* was present. No *Tryonia* were recorded (S. Parmenter 2020, *pers. comm.*). Again, the site was surveyed in 2017 for The Nature Conservancy's 2017 Expert BioBlitz, and only the Sanchez pyrg (*Pyrgulopsis sanchezi*) was recorded at the site by native aquatic biologist K. Guadalupe (S. Parmenter 2020, *pers. comm.*). Ongoing springsnail threats at this spring include invasive red-rimmed melania, both historically and after the spring renovation. In contrast to these reports, a BLM biologist visited Shoshone Spring in January 2020, and noted the presence of *Tryonia* as common (C. Lange 2020, *pers. comm*.). Future surveys are needed to determine if the Amargosa tryonia has recolonized, or otherwise returned to common abundance. Overall, the current condition of the spring is best characterized as moderate.

5.1.22 Unnamed Spring near Tecopa (Tecopa, CA)

No recent data currently exists for an unnamed spring near the large marsh adjacent to the town of Tecopa (Inyo County, California). The original species description for Amargosa tryonia (Hershler and Sada 1987, entire) included reference to such a spring. There is no additional information about this spring beyond the 1987 species description. Overall, the best available information suggests the current condition of the spring unknown.

5. 2 Summary of Current Conditions by Species

5.2.1 Amargosa tryonia (Tryonia variegata)

Resiliency (*high*)—Amargosa tryonia occurred historically at 19 locations in the Amargosa Valley region, with locations on (n=13) and near (n=4) the Ash Meadows NWR. At present, this

species occurs minimally at 12 springs. Several springs exist where this species has lost historically-described habitat, including the presently recorded dry or drying habitats of Chalk, North of Collins Ranch, and Near Crystal Reservoir (USGS 2018, entire; Service 2020, entire), and the heavily modified South of Clay Pits Spring (USGS 2018, entire). However, with these exceptions, the Amargosa tryonia occurs in most historical habitat locations where it was initially described, and nearly all of these are now protected areas of the Ash Meadows NWR to some degree, where human disturbance is stabilized. Many of these sites also exhibit a range of invasive species, historic and ongoing water diversions and other threats. The interactions of these multiple threats is complex and unstudied, and the Amargosa tryonia maintains variation in abundance from abundant to scarce.
Redundancy (*high*)—Recent surveys for Amargosa tryonia verified the species at one NPS location (Devils Hole) and 11 spring locations on the Refuge: Kings Pool, Point of Rocks spring province, Collins Ranch Spring, Five Springs province, Marsh Spring, Mary Scott Spring, North and South Indian springs, North and South Scruggs springs, and School Spring. Amargosa tryonia may also occur on private land at the South of Clay Pits Spring, and in Shoshone Spring on private land outside the Refuge. Unlike all other species in this report, Amargosa tryonia is widespread regionally and occurs at many locations. As such, additional populations may be located in the future. For example, 2014 report from the Mojave Desert Network Inventory and Monitoring program noted springsnails at Saratoga Spring in Death Valley National Park (Moret et al. 2014, entire). A publication describing this assumed range extension for the Amargosa tryonia is in preparation by Dr. Robert Hershler (Smithsonian Institute).
Representation (*high*)—The species is relatively widespread across the Refuge, occurring in habitats of high elevation such as Devils Hole and Five Springs Province, moderate elevation such as North and South Indian Springs, and low elevation at the South of Clay Pits Spring. Habitats vary from large springs with high flow to small springs with little flow (or no outflow in Devils Hole). Occupied springs are also separated by considerable geographic distances across the Refuge, and thus expected to confer genetic differences among demographically distinct populations.

5.2.2 Ash Meadows pebblesnail (Pyrgulopsis erythropoma)

Resiliency (*high*)—At present the condition of these springs is secure against most of the threats, with only limited impacts from human disturbance. In the past these spring habitats (especially Kings Pool and the lowermost Point of Rocks springs (#35, #36 and #37) have been restored to natural conditions, and have stabilized. The population of this species is considered generally abundant at these sites. Both Kings Pool and the Point of Rocks spring province are protected as a major destination at the Ash Meadows NWR, and designated boardwalks offer partial protection from Kings Pools, but less at Point of Rocks springs. The uppermost and smaller outflows at Point of Rocks can exhibit dense sawgrass leading to little suitable habitat. Still, overall resiliency is high for this species despite the limited distribution.
Redundancy (*low*)—Ash Meadows pebblesnail is a specific pyrg endemic to the Kings Pool and several outflows at the Point of Rocks springs province. Not all of the outflows (n=6) support this pyrg, likely four of six at present. The outflows of the Point of Rocks spring province are geographically quite close [within 200 m (~ 650 ft)] and we consider the level of redundancy

low, as a single catastrophic event would likely affect all springs of the Point of Rocks province. The larger spring at the nearby Kings Pool we consider separately given this site is likely demographically independent from the smaller Point of Rocks springs.
Representation (*low*)—The species occurs in springs characterized by both large flow (Kings Pool), and both moderate and small discharges from the Points of Rocks spring province. Other ecological differences of these habitats that potentially contribute to representation are unknown. Population genetic variability is unknown, and given limited geographic proximity of the species range, we suspect representation is low.

5.2.3 Crystal springsnail (Pyrgulopsis crystalis)

Resiliency (*high*)—Despite the limitation of approximately 1 m^2 (~ 11 ft^2) of habitat, the species remains since its description in 1987. Crystal Pool, and the outflow compose the largest spring system at Ash Meadows, supporting a large reservoir downstream. Thus, this spring (and springsnail) is likely the most secure in terms of natural fluctuations in discharge, and has been so against groundwater pumping in the past. Abundance of this species is difficult to quantify given it occurs in a deep pool not logistically amenable to standard sampling. The present abundance is scarce via the capture methods applied throughout this evaluation, but significant challenges in capture technique exist at the site. There are threats of invasive species, both fish and invertebrates at this site that likely impact this system, but they increase with distance downstream and there impacts may be more limited at the spring orifice. Also, some soils and vegetation disturbance is present from recreation, although mitigated by trails and boardwalks. The site is attached to the Visitor Center and Refuge Headquarters, and is considered as both restored and in stable condition. Available information suggests that this species is resilient to these ongoing threats and considered high.
Redundancy (*none*)— The Crystal springsnail is site-specific pyrg, and is endemic to a single spring orifice at Crystal Spring, on the Ash Meadows NWR. As initially described, and at present, all individuals occur at the orifice of the spring pool. The entire known habitat is approximately 1 m^2 (11 ft^2) of habitat surrounding the spring orifice. There is no redundancy for this species.
Representation (*none*)—The extreme limitation in habitat results in a single, extremely small population. We don't expect any significant behavioral, ecological, or genetic variation within this species.

5.2.4 Fairbanks springsnail (Pyrgulopsis fairbankensis)

Resiliency (*high*)—The Fairbanks springsnail is currently abundant. It is found at the orifice and extends downstream at least 1000 m (3280 ft). As one of large springs in Ash Meadows, historical manipulation has impounded, deepened, and narrowed the stream channel. The site now appears stable after acquisition into the Refuge approximately 35 years ago. The site also supports nonnative fishes and predatory and competitive snails. The present distribution has not changed since the species was described, and seems robust to human perturbation and invasive species. Resiliency for the Fairbanks springsnail is high.

Redundancy (*none*)— The Fairbanks springsnail is site-specific pyrg, and is endemic to a single spring outflow at Fairbanks Spring, on the northern extreme of Ash Meadows NWR. As initially described, and at present, individuals occur at the orifice of the spring pool and extend downstream. There are no redundant populations.
Representation (*none*)—There is only one spring and demographic unit for this species. We don't expect any significant behavioral, ecological, or genetic variation within this population/species.

5.2.5 Point of Rocks tryonia (Tryonia elata)

Resiliency (*moderate*)—At present the habitat of these springs is stable, and secure against most of the typical threats of spring modification, with only limited impacts from human disturbance. In the past these spring habitats at Point of Rocks (#35, #36 and #37) have been both manipulated, and since restored to approximate natural conditions. The Points of Rocks tryonia occupies areas with silt and extremely fine sediments. Most of the restored habitat here improved areas that favored gravel and sand, more typical habitat of the co-occurring endemic pyrg. The low flow outflows with habitat best suited to the Point of Rocks tryonia is more limited. At two of the three outflows where *Tryonia* occur, their abundance was scarce during the last survey (but abundant at the third outflow). Of additional importance is that these low discharge environments can be overgrown by grasses to the extent that little surface water remains, and potentially at risk during natural fluctuations in discharge. Resiliency varies among the outflows at Point of Rocks with respect to the Point of Rocks tryonia, and resiliency is estimated as moderate overall.
Redundancy (*low*)—The Point of Rocks tryonia is a site-specific pyrg endemic to the Point of Rocks springs province. Not all of the six outflows support this pyrg. Recent surveys found this *Tryonia* at three of the six outflows. All the outflows of the Point of Rocks spring province are geographically quite close (within several hundred meters) and we consider the level of redundancy low, as a single catastrophic event would likely affect all springs at the Point of Rocks province.
Representation (*low*)—The species occurs in small to moderate size outflows that are all part of the Point of Rocks spring province. Any significant ecological differences among these habitats that potentially contribute to representation are unknown. Each exhibits similar ecological characteristics. Population genetic variability is similarly unknown, but given the approximate geographic distances across all springs [~200 m (650 ft)], we don't expect adaptive differences among the outflows. We estimate representation for the species is low.

5.2.6 Distal-gland springsnail (Pyrgulopsis nanus)

Resiliency (*moderate*)—The Five Springs province and Mary Scott Spring were highly modified springs prior to the Refuge establishment. Much of Five Springs was channelized, and Mary Scott Spring was impounded at the source. Additionally, the Five Springs province supports invasive red-rimmed melania co-occurring with native springsnails, while Mary Scott and Collins Ranch springs do not. At present, *Pyrgulopsis* are common in abundance at all three springs. Recent visits in 2018 by USGS (unpubl.) found low spring discharges (less than 1 L/m)

at Five Springs province and Mary Scott Spring, and are susceptible to natural fluctuation in spring discharge. The abundance and threats at these site confer a moderate level of resiliency.
Redundancy (*moderate*)— The distal-gland springsnail is endemic to four springs in the central area of Ash Meadows NWR (Five Springs province, Mary Scott, Collins Ranch, and North of Collins Ranch springs). One spring, the North of Collins Ranch Spring, is believed to be dry. The remaining three spring sources are approximately 2.5 km (1.6 mi) and 3.2 km (2.0 mi) apart in linear fashion, north to south respectively. Outflows at Five Springs coalesce into a single stream, while Mary Scott and Collins Ranch springs are single, independent outflows. The three spring sources supporting this species are demographically independent populations and collectively provide moderate redundancy.
Representation (*moderate*)—The species occurs in three small to moderate size outflows near the center of Ash Meadows. Significant ecological differences among these habitats that potentially contribute to representation are unknown. Population genetic variability is similarly unknown, but given the moderate geographic distances among the three springs, we may expect some genetic differences among sites. We estimate representation for the species is moderate.

5.2.7 Median-gland springsnail (Pyrgulopsis pisteri)

Resiliency (*moderate*)—The median-gland springsnail was common in Marsh Spring and in North Scruggs springs, and rare in School Spring when described. However, significant impacts affected these habitats 35 years ago. Marsh Spring was impounded by a small dike 30 m (98 ft) below the source causing surface flow to disperse. Other historic impacts included trampling from wild horses, and invasive fish. Under Refuge ownership these areas are potentially more secure since removal of nonnative fishes, and structures that impact free-flowing water. At present, species abundance is common and abundant in North Scruggs and School springs, but scarce in Marsh Spring (USGS 2018, entire). All three springs are threatened today by the red-rimmed melania. Overall, the species viability at present is moderate.
Redundancy (*moderate*)—The present distribution for the median-gland springsnail includes three small to moderate-size springs in close geographical proximity (Marsh Spring, North Scruggs, and School springs). Although discharge from North Scruggs Spring coalesces with South Scruggs Spring approximately 30 m (98 ft) from the source, the species does not occur in South Scruggs Spring. All springs for this species occur in the Warm Springs area of the Refuge. Redundancy is estimated as moderate.
Representation (*low*)—The species occurs in three springs, and are considerated separate demographic units. All three habitats are geographically proximate (500 m; 1,640 ft), and characterized by similar ecological features. Any significant ecological differences among these habitats potentially contributing to representation are unknown. Population genetic variability is similarly unknown. We estimate representation for the species is moderate.

5.2.8 Minute tryonia (Tryonia ericae)

Resiliency (*moderate*)—The North of Collins Ranch Spring was initially described as a small spring with a shallow outflow of 100 L/min (26.4 gal/min). North Scruggs Spring is larger and described above for the median-gland springsnail. Tryonia were historically common in the sediments at these springs. Conversely, recent surveys determined that the North of Collins Ranch Spring was dry in 2018 (USGS 2018, unpubl., entire), and nearly dry in 2020 (Service 2020 unpubl., entire). The present condition of North of Collins Ranch Spring is little to no water, with dense vegetation occurring at the spring. No significant impacts other than drought conditions are noteworthy, and it is unknown why the North of Collins Ranch Spring lacks adequate discharge, but may be the result of natural variation in terrestrial vegetation, or changes in hydrology in combination with naturally low flow. Recent surveys for larger, North Scruggs spring, in 2018 estimated discharge at less than 60 L/min (16 gal/min) (USGS 2018, entire). The North Scruggs habitat has been restored by the Refuge to remove some nonnative competitors and predators, but it still threatened by red-rimmed melania. The abundance estimate for North Scruggs by USGS in 2018 for minute tryonia was common. Overall, recent surveys suggest that low flow and drought conditions may have reduced the occurrence of minute tryonia from two populations to one, occurring at present only at North Scruggs Spring. The estimated resiliency for this species is moderate.

Redundancy (*low*)—The minute tryonia is known from only two small springs in close geographical proximity: North of Collins Ranch and North Scruggs springs. Both springs are located in the central part of the Refuge, approximately 2 km (1.2 mi) apart. Redundancy is considered low.

Representation (*very low*)—The species at present only occurs in a single habitat. Neither ecological nor genetic variation is expected to significantly contribute to representation in this species. Representation for the minute tryonia is very low.

5.2.9 Sportinggoods tryonia (Tryonia angulata)

Resiliency (*high*)—Sportinggoods tryonia occurred historically at these three locations, and still does at present. Abundance was common at Fairbanks and Crystal springs, but scarce at Big Spring in the past. Currently, springsnails are abundant in Crystal Spring and scarce in Fairbanks and Big Spring (although numbers increase significantly toward the spring source in Big Spring). All of these sites were subject to major spring modifications in the past, such as channelization in Fairbanks Springs, water diversion at Big Spring, and direct pumping from Crystal Spring. While Refuge management has mitigated some of these threats today, such as improved vegetation and past impacts to the spring pool, all sites continue to be impacted by aquatic invasive species, including red-rimmed melania, invasive fishes, and crayfish. The habitat at Big Spring is on schedule to be renovated to remove nonnative fishes in the near future pending funding (Corey Lee 2017, personal communication). In general, these large springs are buffered against natural variation in spring discharge that may threaten springs of smaller sizes in times of drought, and appear to support springsnails with ongoing threats exclusive of water. The resilience of Sportinggoods tryonia is high.

Redundancy (*moderate*) — The Sportinggoods tryonia occurs at three large springs on the Refuge (Fairbanks, Crystal, and Big springs), each of which is geographically and demographically distinct from each other.

Representation (*moderate*) — The habitats supporting this species are characterized by similar ecological features. Any significant ecological differences among these habitats potentially contributing to representation are unknown. Population genetic variability is similarly unknown.

However, each habitat is demographically independent, and geographically isolated across the Refuge, spanning approximately 14.2 km (8.8 mi) north to south (Fairbanks Spring to Big Spring), and as such may contribute to population genetic differences. We categorize representation a for the Sportinggoods tryonia as moderate.

5.3 Unknowns/Uncertainties

Some level of uncertainty exists surrounding the data used to classify and evaluate springsnails in this report. Challenges to accurately determine springsnail occurrence stem from several aspects directly related to sampling. First, the small body-size of springsnails may cause them to go undetected when in fact they do occur. Related to body size is the general difficultly in species identification. While generic differences are evident to trained professionals, specific identification requires special tools, chemicals, and training, and thus species occurrence here was assumed based solely genus-level differences. Also, seasonal variation alters the extent of wetted habitat, and access to water required to sample. The time between sampling events for understudied organisms is sometimes great, and intended habitats may look so dissimilar that it is difficult to assume the microhabitats selected are analogous. Finally, the efforts and technique associated with finding surface water amidst the heavy vegetation in arid environments sometimes requires great skill, and the level of training undoubtedly varied across surveys.

6.0 Potential Future Conditions – Species Viability

The viability of the nine species of springsnails depends on maintaining resilient, redundant, and representative populations over time. Uncertainties exist regarding what conditions may be like in the future that may affect the 3Rs. The future use of springs on private land is an important unknown, which pertains to one spring in this assessment. An existing or future landowner may take some action that reduces or eliminates springflow, springsnail habitat, or populations at a spring. Other uncertainties include introduction or continued occurrence of nonnative species such as mosquitofish, red-rimmed melania, crayfish, and various species of aquatic plants. Potential changes in future precipitation levels and temperatures could exacerbate, for example, drought conditions, or potential groundwater pumping and withdrawals; both of these conditions could reduce spring discharge, but there is uncertainty concerning the level of impacts to various springs and thus, a species' response to these threats. If a reduction of spring discharge or free-flowing water occurs, it may be difficult to determine which threat is causing the change.

To address uncertainties of future conditions and the viability of the springsnail species, we developed three scenarios to evaluate the most significant threats and their likely impacts on the resiliency, redundancy, and representation of each species. First we describe the considerations we took when evaluating the 3Rs for each springsnail species. Next, we describe the three scenarios we developed and evaluated. Finally, we present 3Rs descriptions of each species and their habitat with respect to each of the future scenarios.

6.1 Consideration for Springsnail 3Rs

Resiliency. Resiliency is the ability of a species to withstand environmental and demographic stochasticity (see Section 2.2). It is measured based on metrics of population health, such as the size and growth rate of populations and how quickly they are able to rebound in numbers after an event results in loss of individuals or populations. Based on survey data as early as the 1980s and most recently from 2020 within the analysis area, we can conclude that many springsnail populations can recover or stabilize from anthropogenic disturbances such as impoundment, channel modification, and surface water diversion, that have the potential to result in initial individual- and population-level impacts. Isolated populations of endemic aquatic invertebrates may be resilient to short-term temporal population declines (Martinez and Sorensen 2007, p. 31). Springsnail populations cannot, however, be resilient if their resource needs—water quality, substrate and vegetation, free-flowing water, and adequate spring discharge—are not being met. Based on this, we assume that reductions in population size or extent of occupied habitat cause reduction in resiliency.

Determining what may occur to springs on private land is not possible. If drought conditions prevail in the future, water availability may be further reduced relative to human demand. Springs on private land may be modified in multiple ways in order to meet water demands, such as irrigation, livestock watering, and domestic use. Impacts to springs could include vegetation and soil disturbance, water pollution, groundwater pumping, and spring modifications (i.e., surface water diversion, channel modification, or impoundment). Assessing which threats are likely to occur in the future is both challenging and site-specific. Uncertainties also exist at springs on State and Federal lands because stochastic events are random and cannot be predicted.

Groundwater pumping, and altered precipitation and temperature could result in a reduction of adequate spring discharge and free-flowing water for springsnail populations. Lowered discharge may reduce the amount of suitable vegetation and substrate available. Since we cannot predict the extent of such water reductions, we consider resiliency under three potential reduced-springflow scenarios.

We considered several factors in evaluating the resiliency of the springsnail species. Survey results and studies indicate that springsnail species may be highly fecund or in other words, are able to produce high numbers of offspring quickly (Mladenka and Minshall 2001, pp. 208–209; Brown et al. 2008, p. 485). While birth and death rates of springsnails are not fully understood, we assume the fecundity or birth rates of springsnails would allow these populations to rebound from disturbance. Second, populations of these springsnails demonstrate some level of resilience based on continued observations despite significant disturbances, such as spring modifications in the past, sometimes with lasting effects. Third, we assume that populations that occupy greater lengths of habitat are more resilient due to size, as habitat destroyed in lower reaches might not affect individuals in the headwaters. In other words, an entire springsnail population is less likely to be extirpated by a single stochastic event if it occupies a greater length of habitat.

Redundancy. Redundancy is defined at the species level and is a measure of a species' ability to withstand catastrophes (see Section 2.2). Compared to resiliency, redundancy is about spreading the species-level risk, as measured through the distribution of populations (or individuals in a large population) across the species range. In relevance to this report, all springsnail species occur in small- to moderate-sized, geographically isolated populations. However, the nine springsnail species vary across a spectrum of distribution from regionally distributed in at least 12 populations for one species, compared to other species where distribution is limited to a single spring. Redundancy guards against potential species-level risks, such as wildfires, intense drought, variable precipitation, and groundwater pumping.

To evaluate redundancy, we considered the number of populations of each springsnail species. For those species with more than one population, we factored in the distance between each population. We also considered whether each species has populations sufficiently distributed across its range or in other words, populations that occur in different hydrographic basins or with landscape features that provide physical separation between populations (valleys, mountains, forests, etc.) provide physical separation between the populations. We assume that a species has higher redundancy if populations are further apart because a catastrophic event would be less likely to impact each population.

Representation. Representation is the ability of a species to adapt to both near-term and long-term changes in its physical and biological environments (see Section 2.2). It can be measured through ecological diversity (environmental variation) and genetic diversity within and among populations. Many species of springsnails have likely existed within their current spring distribution since the Pleistocene Epoch (approximately 12,000 years ago) and earlier since the late Tertiary era (approximately 2.6 million years ago) (Hershler and Liu 2008, p. 100). The genetic diversity of springsnail populations, as it relates to their ability to adapt over time to long-term changes in the environment, has not been extensively studied for the species reviewed in this report. Given the long period of time springsnail populations have occurred in their respective springs and spring provinces, we assume they can withstand and adapt to some perturbations in their physical or biological environments; however, that adaptive ability may be species and spring system specific. Within the springbrooks inhabited by a given species, the areas of springbrook occupied could have a range of specific combinations of physiochemical characteristics tolerable by that species (Sada 2017, p. 13). The long-term isolation and small area within some spring systems, though, may make springsnails weakly adapted to survive introduced predation and competition, subsequently elevating the risk of extirpations in some populations of springsnail species (Sada 2017, p. 11).

Species-specific genetic and ecological diversity information is limited or lacking for these springsnail species. Therefore, in order to evaluate representation, we consider the diversity of physical and biological environments in which each species occurs. In particular, we considered differences in elevation, habitat variability, and variability of water parameters (e.g., water temperatures, flow rates, DO) between and within populations. We assume a species with greater diversity of environmental conditions has higher representation.

6.2 Future Scenarios

In consideration of the uncertainties related to future conditions, we developed three future scenarios that are reasonable over the next 50 years:

1) Springs maintain springflow or discharge similar to current conditions
2) Springs experience reduction in springflow or discharge
3) Springs experience extreme reduction in springflow or discharge or it is completely eliminated; flow and discharge are inadequate

6.2.1 Scenario 1: Springs maintain springflow or discharge similar to current conditions.

Resiliency. If springflow at springs does not change over the next 50 years, we anticipate springsnails to maintain their current levels of resiliency (see Chapter 5.0 and Appendix B). It is also possible that springs may undergo future restoration activities, thereby improving their overall habitat condition.

In order to maintain discharge at springs under *Scenario 1*, we expect that water conservation measures relating to agricultural and domestic use in the Amargosa Valley will continue (see Chapter 4.1, Hydrology and Water Management). Additionally, the recent findings and delineation of a transmissive megachannel in underlying carbonate rocks may extend protected areas from excessive groundwater drawl to offer more protection in the future.

We expect most unforeseen stochastic events (e.g., flooding and wildfire), particularly on Federal and State lands, to be repaired through habitat restoration and reintroduction efforts, if needed. Certainty of responsive action is higher for Federal and State lands because of their land-management regulations. We are uncertain if habitat and populations would be restored on private lands. Restoration or reintroduction efforts would likely help populations rebound at these sites. Even with adequate spring discharge, populations may be extirpated if stochastic events are severe enough, and restoration activities do not or cannot occur.

We would expect population resiliency to remain the same as current conditions for stochastic events under *Scenario 1*, since springflow and discharge will remain adequate.

Redundancy. Springflow and discharge would remain adequate over the next 50 years in response to groundwater pumping and altered precipitation and temperature. We would expect most species' populations to remain and not become extirpated. Those species with one or few populations may not be able to withstand a large catastrophic event, possibly becoming extirpated if impacts are significant, even if flows and discharges remain adequate. This may also hold true for populations on private lands where conservation plans and measures are not in place. Those species with numerous populations would likely withstand such events. Many uncertainties exist under this scenario depending upon the type and extent of catastrophic event (water diversion, wildfire, earthquake, etc.).

Representation. Maintaining adequate springflow and discharge over the next 50 years should maintain genetic diversity in all springsnail populations similar to current conditions, as long as habitat changes or other disturbances do not occur at the population or rangewide levels. Thus, representation would be maintained at current levels.

6.2.2 Scenario 2: Springs experience some reduction in springflow or discharge.

Resiliency. If springflow and discharge are reduced over the next 50 years due to groundwater pumping, altered precipitation and temperature, or both, populations or species' conditions may be reduced from current conditions. While a reduction in water quantity alters pH and DO concentration (Sada et al. 2015, p. 45), water quality is likely to remain adequate. A reduction in spring discharge results in a decrease in habitat size, including springbrook length and wetted width (Sada et al. 2015, p. 45). For example, Morrison (2013, p. 12) found substantial decreases in habitat (water depth and habitat size) with only small discharge reductions; the rate of change was greatest with only a 10 percent reduction in springflow. Thus, a decrease in habitat and water quality is dependent upon the quantity of flow reduction. Overall, these types of changes are likely to reduce population abundance due to reduction in habitat size.

Future conditions at each spring, with some reduction of discharge, would likely be lower to an unknown degree compared to current conditions. Discharge would diminish and the amount of available habitat could decrease. Depending on the amount of discharge reduction, free-flowing water may be modified. If the quantity of water is reduced in a spring that currently has low water levels, the modified future levels may be so low that portions of the springbrook are no longer under water. For future conditions tables presented later in this chapter, a reduction in spring discharge may result in a corresponding reduction in two habitat needs (i.e., aquatic vegetation and substrate, and free-flowing water). Springs could then see a full decline in their overall condition (high to moderate, moderate to low, etc.). See below for future spring conditions and summaries of resiliency for each species under *Scenario 2*. Springs would likely be more affected by stochastic events under *Scenario 2*, thereby potentially causing more significant population- or rangewide-level impacts to populations than under *Scenario 1*.

Redundancy. Under this scenario, reduced springflow may cause the loss of some springs or populations, resulting in a decline in redundancy. Some populations may have reduced redundancy from historical conditions due to decreased habitat and decreases in free-flowing water. Those species with multiple populations, however, would have greater redundancy, thus more resilient to catastrophic events that result in reduced flows and discharge than those with fewer populations. Also, those springs on lands with management or conservation plans may undergo management actions to offset resiliency loss, thereby increasing redundancy and persistence. See below for summaries of redundancy for each species under *Scenario 2*.

Representation. We would expect a drop in resiliency in most populations over the next 50 years. If populations with low resiliency were to be extirpated, those species would see a loss of representation. Extirpation of a species that occurs in only a single population would result in the loss of that species. See below for summaries of representation for each species under *Scenario 2*.

6.2.3 Scenario 3: Springs experience a significant reduction in springflow or discharge, or completely eliminated. Flow and discharge are inadequate.

Resiliency. Flows and discharges that are inadequate over the next 50 years would likely result in the extirpation of all affected springsnail populations, since two of their basic needs would be eliminated. In addition, a significant decrease in free-flowing water and spring discharge would also decrease sufficient suitable vegetation and substrate. Based on these factors, there would be a significant reduction in resiliency for all springsnail species.

Redundancy. Populations with inadequate flow and discharge would experience reduced redundancy since an unknown number of populations would likely become extirpated. It is not possible to estimate if any populations may be able to survive under such dire conditions, but we assume that extirpation is likely because three of their four physical and biological needs would not be met.

Representation. Under this scenario, we would expect most springsnail populations to be extirpated over the next 50 years as water quantities would not likely be adequate for survival. Species that may not be extirpated would experience a significant reduction in representation.

6.3 Future Condition Species Summaries for 3Rs

We use the best available scientific and commercial information to estimate the likely future conditions of the nine species of springsnails under three scenarios. Our goal is to describe the viability of the species in a manner that will address the needs of the species in terms of resiliency, redundancy, and representation. The following sections summarize the conditions presented under the three scenarios. Overall, these summaries take into account a combination of the species needs, current condition, and potential future conditions given the outcomes for the three scenarios.

6.3.1 Amargosa Tryonia (Tryonia variegata)

Amargosa tryonia current and future viability by population is presented in Table 6.3.1, below.

Scenario 1 represents the maintenance of spring discharge and associated current conditions of the Amargosa tryonia. At present, the species occurs in at least 12 springs or spring provinces and at least three general areas on the Ash Meadows NWR. Additionally, this species may occurs at two sites farther downgradient in Amargosa Valley at Shoshone Springs and an unnamed spring near the marsh by Tecopa. This species exhibits high population redundancy. Also, with few exceptions noted below (Table 6.1), most Refuge springs and the Shoshone

Spring have been restored for aquatic and riparian conservation. These sites are resilient against further negative modifications (i.e., surface water diversion, impoundments, channel modification), and against any significant vegetation and soil disturbance (i.e., disturbance resulting from recreation, grazing, and browsing), thus the species is resilient across the majority of the species range with respect to non-water supply threats. Since *Scenario 1* maintains discharge at current levels, we expect species resiliency to remain high, and no further loss in redundancy. Still, there are three springs recently recorded as dry or nearly so (Chalk Spring, North of Collins Ranch Spring and near Crystal Reservoir Spring). However, with respect to this species, little redundancy is lost since the species occurs in at least 12 sites. The geographical separation among these sites, and the correlative distinctive morphological variation evidenced across the range, we estimate genetic representation for this species as high for the future *Scenario 1*.

Under *Scenario 2*, springs are likely to experience some reduction in discharge, and consequently reduce all species needs, due to climate change (e.g., moderate emissions RCP 4.5) or future groundwater pumping. Given the close geographic proximity and the reliance on the same carbonate aquifer, the ultimate source of water for all the Ash Meadows springs would likely be reduced in concert; however, springs with low flow and potentially those at higher elevation may exhibit reduced discharge before others (i.e., reduced resiliency). Relative to current conditions, the small size of some spring habitats could potentially change to Low Condition (i.e., Point of Rocks Spring Province, Five Springs Province, Last Chance Spring, Marsh Spring, Mary Scott Spring, North and South Indian Springs, North and South Scruggs Springs, and School Spring), or become dry (North of Collins Ranch Springs, Chalk Spring, and South of Clay Pits Spring), resulting in lowered redundancy for Amargosa tryonia in *Scenario 2* (Table 6.1). The lowest discharge, and highest elevation springs may be affected first.

Scenario 3 is the most severe scenario considered, and is characterized by significant reduction in discharge potentially associated with higher climate change emission pathways (e.g., RCP 8.5) or increased groundwater pumping. Springs that are currently High Condition would likely become less resilient to stochastic perturbation, and many moderate- and low-condition springs would likely become dry. Overall, the species would exhibit lower redundancy than anticipated with *Scenario 1* or *Scenario 2*. The increased risk of extirpation of populations could also reduce the high level of representation evidenced at geographically disparate populations. Based on lowered discharge relative to the current conditions, potentially 12 of the known 19 sites considered here would be at increased risk of extirpation due to inadequate groundwater supply.

Table 6.3.1. Amargosa tryonia current and future viability by population.

	Current Conditions of Species Needs				Future viability		
Population	Water Quality	Substrate and Vegetation	Free-Flowing Water	Adequate Discharge	Future Scenario 1	Future Scenario 2	Future Scenario 3
Kings Pool	Adequate	High	High	Adequate	High	Moderate	Low
Point of Rocks Spring Province	Adequate	Moderate/ Low	High	Moderate /Low	Moderate/ Low	Low	Low
Chalk Spring	-	-	-	Dry	Dry	Dry	Dry

	Current Conditions of Species Needs				Future viability		
Population	Water Quality	Substrate and Vegetation	Free-Flowing Water	Adequate Discharge	Future Scenario 1	Future Scenario 2	Future Scenario 3
Collins Ranch Spring	Adequate	Moderate	High	Adequate	High/ Moderate	Moderate	Low
North of Collins Ranch Springs	-	-	-	Low/Dry	Low	Dry	Dry
Five Springs Province	Adequate	High	High/ Moderate	Adequate	Moderate	Low	Low
Last Chance Spring	Adequate	Moderate	Moderate	Moderate /Low	Moderate/ Low	Low	Low
Marsh Spring	Adequate	Moderate	Moderate	Adequate	Moderate	Low	Dry
Mary Scott Spring	Adequate	Moderate	Moderate	Adequate	Moderate/ Low	Low	Dry
North Indian Spring	Adequate	Moderate	Moderate	Adequate	Moderate/ Low	Low	Dry
South Indian Spring	Adequate	Moderate	Moderate	Adequate	Moderate	Low	Dry
North Scruggs Spring	Adequate	Moderate	Moderate	Adequate	Moderate	Low	Dry
South Scruggs Spring	Adequate	Moderate	Moderate	Adequate	Moderate	Low	Dry
School Spring	Adequate	Moderate	Moderate	Adequate	Moderate	Low	Dry
South of Clay Pits Spring	unknown	Moderate	Low	Low	Low	Dry	Dry
Near Crystal Reservoir Spring	-	-	-	Dry	Low/Dry	Dry	Dry
Devils Hole	Adequate	Adequate	-	Adequate	High	Moderate	Low
Tecopa, CA	unknown	unknown	unknown	unknown	unknown	unknown	unknown
Shoshone, CA	Adequate	Adequate	Adequate	Adequate	moderate	unknown	unknown

- (dash) denotes springflow too low to assess condition or data otherwise available.

6.3.2 *Ash Meadows Pebblesnail (Pyrgulopsis erythropoma)*

Future *Scenario 1* represents continuation of current condition of the Ash Meadows pebblesnail. The present distribution for this species includes one larger habitat (Kings Pool) and several smaller spring outflows (Points of Rocks springs) in the area around Points of Rocks. The entire species range spans only 200 m (650 ft) across. Relative to springsnails species occurring at multiple geographic localities, and across environmental gradients, this species shows little redundancy or representation. However, given the past habitat restoration and protections afforded by the Ash Meadows NWR, these populations exhibit resilience against future disturbance that negatively affects water quality, substrate and vegetation, or impoundment. As such the future threats for Refuge springs, if any, likely result from inadequate discharge. As *Scenario 1* is defined as the maintenance of current conditions with respect to discharge, *Scenario 1* does not decrease viability of the Ash Meadows pebblesnail.

Under *Scenario 2*, springs are likely to experience some reduction in discharge, and consequently reduce resiliency at all springs. The larger spring associated with Kings Pool, offers considerable habitat, and some reduction is discharge associated with *Scenario 2* would not be catastrophic, however, the smaller springs at Point of Rocks, if decreased proportionally, would lower current conditions from already moderate or low. In this scenario, the lowest discharge outflows (Unnamed #38, #39 and #40) might cease to flow, and result in further decreases in species redundancy.

Significant reduction in spring discharge associated with *Scenario 3* would drastically reduce viability for a species with a distribution at one general location. The smaller Points of Rocks springs would likely lose resiliency and would be at increased risk of extirpartion. The largest outflow at Point of Rocks, excluding Kings Pool, however, might remain as wetted habitat. The large spring feeding Kings Pool would likely lose resiliency as well, but still provide habitat for springsnails. During the peak groundwater pumping in the 1970s by Devils Hole [less than 6 km (3.8 mi) away], the largest Point of Rock spring was reduced by almost half from 0.85 to 0.46 cfs (Halford and Jackson 2020, p. 87). However, the Kings Pool was less affected and only dropped from 2.70 to 2.65 cfs during peak groundwater pumping.

Table 6.3.2. Ash Meadows pebblesnail current and future viability.

	Current Conditions of Species Needs						
Population	**Water Quality**	**Substrate and Vegetation**	**Free-Flowing Water**	**Adequate Discharge**	**Future Scenario 1**	**Future Scenario 2**	**Future Scenario 3**
Kings Pool	Adequate	High	High	Adequate	High	Moderate	Low
Point of Rocks Spring Province	Adequate	Moderate/ Low	High	Moderate /Low	Moderate/ Low	Low	Low

6.3.3 Crystal Springsnail (Pyrgulopsis crystalis)

Future *Scenario 1* represents the maintenance of spring discharge and current conditions of the crystal springsnail. The present distribution for this species includes only a single habitat (Crystal Pool). This springsnail only exists at the spring orifice approximately 1 m^2 (~11 ft^2) in area. The exceptionally small habitat supports a population with scarce abundance, and likely affords no significant redundancy or representation in *Scenario 1*. However, the habitat at Crystal Spring is characterized by one of the most protected sites at the Ash Meadows NWR. The Visitor Center and Headquarters are located near the spring, and this site remains the focus of quality restored habitat. Thus, threats unrelated to spring discharge (e.g., invasive species, human disturbance) are mitigated. At present, adequate discharge is available to maintain this species. Despite no redundancy or representation, this single small population (and species) is highly resiliency at current conditions, and expected to continue in future *Scenario 1* (Table 6.3).

Under *Scenario 2*, Crystal Spring is likely to experience some reduction in discharge, and consequently reduced resiliency due to a smaller habitat at its single population. However, because Crystal Spring is the largest spring at Ash Meadows NWR [11,000 l/m (6.5 cfs), Hershler and Sada 1987, p. 841) and one of the largest in the entire Amargosa Valley, some reduction in discharge would be unlikely to drastically affect population viability based on adequate discharge alone. Under *Scenario 2*, we might expect viability to drop from high to moderate overall.

Under the most extreme reduction in discharge scenario, Crystal spring might retain wetted habitat. This spring is not only the largest in size, by also located at the lowest elevation compared to all other springs at the Ash Meadows NWR. With significant decreased spring discharge in this future scenario, potentially associated with lower groundwater levels due to higher pumping and significant climate change emissions pathways (e.g., RCP 8.5), Crystal Spring is likely to be the most resilient habitat on the Ash Meadows NWR, and thus afford low species viability in *Scenario 3*.

Table 6.3.3. Crystal springsnail current and future viability.

	Current Conditions of Species Needs						
Population	**Water Quality**	**Substrate and Vegetation**	**Free-Flowing Water**	**Adequate Discharge**	**Future Scenario 1**	**Future Scenario 2**	**Future Scenario 3**
Crystal Spring	Adequate	High	High	Adequate	High/Moderate	Moderate	Low

6.3.4 Fairbanks Springsnail (Pyrgulopsis fairbankensis)

Future *Scenario 1* represents the maintenance of spring discharge and associated current conditions of the Fairbanks springsnail. The present distribution for this species includes only a single habitat (Fairbanks Spring). Similar to the crystal springsnail, this species only exists at the spring orifice approximately 2 m (~ 6 ft) wide in the headwater pool. Although this hyper-endemic springsnail occurs in an exceptionally small habitat, the species is common in abundance, and we expect the maintenance of adequate species needs into the future for *Scenario 1*. Similar to the crystal springsnail, this population (and species) affords no redundancy or representation in *Scenario 1*. However, the discharge at Fairbanks Spring is also large [6500 l/m (3.8 cfs)], and the population has been resilient against human-mediated structural modifications and invasive species both before, and after the management under the Ash Meadows NWR. As current conditions demonstrate the relatively high resilience of this species in spite of structural disturbance of substrate and invasive species, the viability for the Fairbanks Springsnail is expected to be high to moderate in *Scenario 1.*

Under *Scenario 2*, Fairbanks Spring is likely to sustain some reduction in discharge, and consequently reduced resiliency due to a decreased habitat at its single population. However, because Fairbanks Spring is one of the largest springs at Ash Meadows NWR [11,000 l/m (6.5 cfs), Hershler and Sada 1987, p. 841)] and as well as the entire Amargosa Valley, some reduction in discharge would be unlikely to significantly affect population viability based on adequate discharge alone. Under *Scenario 2*, we expect viability to drop from high/moderate to moderate overall.

Scenario 3 is the most extreme reduction in discharge scenario. Unlike many of the smaller springs, such as those found in the central area of Ash Meadows, might become dry, Fairbanks Spring might retain wetted habitat. This spring is sufficiently large that free-flowing water and partial discharge may sustain springsnails. However, non-water supply threats are expected to continue, and as such, combined with the lower resilience from reduced discharge will likely result in low species viability overall.

Table 6.3.4. Fairbanks springsnail current and future viability.

	Current Conditions of Species Needs						
Population	**Water Quality**	**Substrate and Vegetation**	**Free-Flowing Water**	**Adequate Discharge**	**Future Scenario 1**	**Future Scenario 2**	**Future Scenario 3**
Fairbanks Spring	Adequate	Moderate	Moderate	Adequate	High/ Moderate	Moderate	Low

6.3.5 Point of Rocks Tryonia (Tryonia elata)

Future *Scenario 1* represents continuation of current condition of the Point of Rocks tryonia. The present distribution for this species includes the several small spring outflows referred to as Point of Rocks Springs Province (excluding the nearby Kings Pool). These restored and protected springs vary in discharge, with three smaller springheads (#38, #39 and #40), and three slightly larger springs on below (#35, #36 and #37). The Point of Rocks tryonia is endemic to these several and largely isolated spring channels, and as such exhibits little redundancy or representation at their single locale. However, given the past habitat restoration and protections afforded the Ash Meadows NWR, these populations exhibit resilience against future disturbance that potentially affects water quality, substrate and vegetation, or impoundment. As such the future threats for the Point of Rocks Springs Province, if any, likely result from inadequate discharge. As *Scenario 1* is defined as the maintenance of current conditions with respect to discharge, *Scenario 1* does not decrease viability of the Point of Rocks tryonia. Overall, the moderate discharge, combined with high resiliency, but low redundancy classify this species as high/moderate viability in *Scenario 1*.

Under *Scenario 2*, springs are likely to experience some reduction in discharge, and consequently reduce resiliency at all springs. Reduced discharge associated with *Scenario 2* would not be catastrophic, however, the smaller springs at Point of Rocks Springs Province, if decreased proportionally, would lower current viability to moderate. In this scenario, the lowest discharge outflows (Unnamed #38, #39 and #40) might cease to flow, and result in further decreases in species redundancy.

Significant reduction in spring discharge associated with *Scenario 3* would drastically reduce viability for a species with a distribution at one general location. The smaller Points of Rocks springs would likely lose resiliency. The largest outflow at the Point of Rocks group (#35), however, might afford some resiliency in this scenario. During the peak groundwater pumping in the 1970s by Devils Hole [less than 6 km (3.8 mi) away], the largest Point of Rocks spring was reduced by almost half from 0.85 to 0.46 cfs (Halford and Jackson 2020, p. 87). Species viability for Scenario 3 for the Point of Rocks tryonia would be estimated as very low.

Table 6.3.6. Point of Rocks tryonia current and future viability by population.

	Current Conditions of Species Needs						
Population	Water Quality	Substrate and Vegetation	Free-Flowing Water	Adequate Discharge	Future Scenario 1	Future Scenario 2	Future Scenario 3
Point of Rocks Spring Province	Adequate	Moderate/ Low	High	Moderate /Low	Moderate	Low	Very low

6.3.6 Distal-gland Springsnail (Pyrgulopsis nanus)

The distal-gland springsnail presently occurs in three springs in the central area of the Ash Meadows NWR (Five Springs province, Collins Ranch, and Mary Scott springs). Two of these locations, Five Springs Province and Collins Ranch Spring, have benefitted from restoration efforts of the Refuge, namely channel restoration and vegetative reduction, respectively. However, the North of Collins Ranch Spring appears dry. The distribution of this species is characterized by three variable-sized springs with adequate discharge, distributed as geographically, and demographically separated populations on the Refuge, all of which support this pyrg at present. Maintenance of current conditions in discharge as defined in *Scenario 1* provide moderate levels of resiliency, redundancy, and representation at all three sites. Overall the viability of the distal-gland springsnail is estimated as moderate in *Scenario 1*.

Under *Scenario 2*, springs are likely to experience some reduction in discharge, and consequently reduce resiliency at all three springs. Reduced discharge associated with *Scenario 2* would not be catastrophic, however, but might lower overall viability from moderate to low. Five Springs Province, although previously affected by reduction in free-flowing water by pipework and other modifications, has responded to restoration and is restored to semi-natural conditions and offer the most resiliency. Of the three sites supporting this species, Mary Scott Spring has only moderate to low discharge at the current condition, so *Scenario 2* might potentially reduce all representation and redundancy attributable to this site. Collins Ranch Spring falls intermediate among the other sites for resilience, as this site supports abundant springsnails, but is particularly susceptible to reduction in discharge.

Significant reduction in spring discharge associated with *Scenario 3* would drastically reduce viability for this species in its three populations. Two of three populations (Mary Scott Spring and Collins Ranch Spring) would be at increased risk of desiccation. The overall viability for the distal-gland springsnail is estimated to be low in this scenario, as only the Five Springs Province is at a lower level of risk in this scenario.

Table 6.3.7. Distal-gland springsnail current and future viability by population.

	Current Conditions of Species Needs						
Population	**Water Quality**	**Substrate and Vegetation**	**Free-Flowing Water**	**Adequate Discharge**	**Future Scenario 1**	**Future Scenario 2**	**Future Scenario 3**
Collins Ranch Spring	Adequate	Moderate	High	Adequate	High/ Moderate	Moderate	Low
North of Collins Ranch Springs	-	-	-	Low/Dry	Low	Dry	Dry
Five Springs Province	Adequate	High	High/ Moderate	Adequate	High/ Moderate	Moderate/ Low	Low
Mary Scott Spring	Adequate	Moderate	Moderate	Adequate	Moderate/ Low	Low	Dry

6.3.7 Median-gland Springsnail (Pyrgulopsis pisteri)

Future *Scenario 1* represents continuation of current condition of the median-gland springsnail. The present distribution for the median-gland springsnail includes three small to moderate spring outflows in close geographical proximity (Marsh, School, North Scruggs springs). All three springs are located on the Ash Meadows NWR in similarly restored condition, with species needs met in moderate condition (Table 6.38). The close proximity and similar conditions offers little redundancy or representation at present. These springs are located in a protected area that is off-limits to public use due to their size, high biological integrity, and recent significant efforts to remove non-native species. However, the springflows at these site are susceptible to drought in *Scenario 1*, and overall viability is rated as moderate.

Under *Scenario 2*, springs are likely to experience some reduction in discharge, and consequently reduce resiliency at all springs. Reduced discharge associated with *Scenario 2* would not be catastrophic, however, all three springs would likely sustain similar reductions in flow due to the close proximity, and consequent reduction in resiliency. In this scenario, viability for the median-gland springsnail might be reduced to low condition.

Significant reduction in spring discharge associated with *Scenario 3* would drastically reduce viability for this narrow endemic. Despite the protections afforded against all non-springflow related threats, there is increased risk that all three similar springs could go dry, and increased risk of both extirpation and extinction for this species under *Scenario 3,* thus viability for the median-gland springsnail under *Scenario 3* is estimated to be very low overall.

Table 6.3.8. Median-gland springsnail current and future viability by population.

	Current Conditions of Species Needs						
Population	**Water Quality**	**Substrate and Vegetation**	**Free-Flowing Water**	**Adequate Discharge**	**Future Scenario 1**	**Future Scenario 2**	**Future Scenario 3**
Marsh Spring	Adequate	Moderate	Moderate	Adequate	Moderate	Low	Dry
North Scruggs Spring	Adequate	Moderate	Moderate	Adequate	Moderate	Low	Dry
School Spring	Adequate	Moderate	Moderate	Adequate	Moderate	Low	Dry

6.3.8 Minute Tryonia (Tryonia ericae)

Future *Scenario 1* represents a continuation of current condition of the minute tryonia. The present distribution of the minute tryonia includes only two small spring outflows in close geographical proximity (North of Collins Ranch and North Scruggs springs). The species needs for the current condition (and *Scenario 1*) is presumed adequate for North Scruggs Spring given the occurrence of springsnails, minimal disturbance, and habitat restoration completed by the Refuge. However, as noted above for this spring, the habitat size is susceptible to drought. Unfortunately, the only other spring (North of Collins Ranch Springs) where this species is found no longer supports springsnails, and is recorded as dry during the USGS 2018 survey (see Current Conditions, Section 5). This species at present has lost 50 percent of its historical habitat, and would be unlikely to improve in the future *Scenario 1*. Thus, the species has little redundancy or representation, and only occurs at one site with little resiliency to reduced springflow. The overall condition predicted for *Scenario 1* is moderate.

Under *Scenario 2*, both springs are likely to experience some reduction in discharge, and consequently reduce resiliency. Reduced discharge associated with *Scenario 2* might be catastrophic for the smaller North of Collins Ranch Springs, and would likely decrease condition of the previously moderate North Scruggs Spring to a low future condition.

Significant reduction in spring discharge associated with *Scenario 3* would drastically reduce viability for this narrow endemic. Despite the protections afforded against all non-springflow related threats, there is increased risk that both springs could go dry, and increased risk of extirpation or extinction for the species. Overall species viability for *Scenario 3* for the minute tryonia is estimated to be very low.

Table 6.3.9. Minute tryonia current and future viability by population.

	Current Conditions of Species Needs						
Population	**Water Quality**	**Substrate and Vegetation**	**Free-Flowing Water**	**Adequate Discharge**	**Future Scenario 1**	**Future Scenario 2**	**Future Scenario 3**
North of Collins Ranch Springs	-	-	-	Low/Dry	Low	Dry	Dry

	Current Conditions of Species Needs						
Population	Water Quality	Substrate and Vegetation	Free-Flowing Water	Adequate Discharge	Future Scenario 1	Future Scenario 2	Future Scenario 3
North Scruggs Spring	Adequate	Moderate	Moderate	Adequate	Moderate	Low	Dry

- (dash) denotes springflow too low to assess condition

6.3.9 Sportinggoods Tryonia (Tryonia angulata)

Future *Scenario 1* represents a continuation of current condition of the Sportinggoods tryonia. Presently and historically, the Sportinggoods tryonia inhabits three springs of the Ash Meadows NWR. These three springs (Big, Crystal, and Fairbanks Springs) are among the largest and most secure in terms of water-related threats. As is typical for historically used water sources, these springs have been manipulated for water-flow and impacted by the introduction of non-native species to various degrees, each of these habitats has shown to be resilient in regards to the maintenance of Sportinggoods tryonia. Additionally, each population is geographically discrete relative to each other and suggests independent evolution, a situation that likely confers both redundancy and representation. All species needs are presumed met as this species occurs at all sites at present. Thus, we presume that the future condition as defined in *Scenario 1* would be high.

Under *Scenario 2*, springs are likely to experience some reduction in discharge, and consequently reduce resiliency at all three springs. Reduced discharge associated with *Scenario 2* would not be catastrophic for these large spring habitats, however, some decrease in resiliency drop overall viability from high towards moderate.

An extreme reduction in spring discharge associated with *Scenario 3* would further reduce viability for this species in its three populations. The overall viability for the Sportingoods tryonia would be low in this most extreme scenario, but risk of extirpation at any of these springs would be unlikely.

Table 6.3.10. Sportinggoods tryonia current and future viability by population.

	Current Conditions of Species Needs						
Population	Water Quality	Substrate and Vegetation	Free-Flowing Water	Adequate Discharge	Future Scenario 1	Future Scenario 2	Future Scenario 3
Big Spring	Adequate	High	Moderate	Adequate	Moderate	Moderate	Low
Crystal Spring	Adequate	High	High	Adequate	High	Moderate	Low
Fairbanks Spring	Adequate	Moderate	Moderate	Adequate	High	Moderate	Low

6.4 Cumulative Effects

Threats both currently and in the future may act together to negatively affect springsnails at Ash

Meadows springs or spring provinces. Predation and competition, vegetation and soil disturbance, water pollution, spring modifications, groundwater pumping, and altered precipitation and temperature may adversely affect a site if one, some, or all threats occur concurrently (both now and in the future). Many of the threats are either historical and have stabilized over time, or are current with low-level or individual-level impacts. Potential future conditions from groundwater pumping or altered precipitation and temperature could also produce individual-level effects, but may rise to population-level impacts at specific springs depending on the severity of effects to free-flowing water and spring discharge, and whether or not current threats are concurrently impacting the springs.

7.0 Status Assessment Summary

We used the best available scientific and commercial information to project the likely future conditions for nine species of springsnails. Our results described a range of possible and probable conditions in terms of resiliency, redundancy, and representation, both currently and into the future. The small size, temporal fluctuations in abundance, complex taxonomy and biogeographical and logistical issues during surveys, all contribute to uncertainty in assessing species distributions in this group.

Our information suggests that the threats discussed in this SSA report are already occurring or may occur with similar or increased intensity in the future. Despite limited species-specific information on how habitat change influences each species, springsnails in general seem resilient as a group, as evidenced by their present distribution given historic habitat manipulation and the presence of invasive species. In the case of these Ash Meadows springsnails, nearly all species have received recovery actions associated with the Federal stewardship of the NPS and the Service (Ash Meadows NWR). Actions include both habitat restoration activities and the protection of water resources. Primary among water conservation and management actions include the prohibition of new groundwater pumping within 40 km (25 mi) of Devils Hole. As discussed above, the notable reduction in water levels in Devils Hole and the low discharge from numerous Ash Meadows spring sources associated with a period of intense groundwater pumping for agriculture during the 1970s (Nelson and Jackson 2020, p. 26; Halford and Jackson 2020, p.87), suggest most springsnails populations are resilient against some level of reduced discharge. Despite such general resiliency, some populations are likely extirpated at present, and resulted in decreased viability of three species considered here (see Table 7.1). Potentially for the Amargosa tryonia, minute tryonia, and distal gland springsnail, each species may be extirpated for 4 of 19 (21%), 1 of 2 (50%), and 1 of 4 (25%) populations, respectively.

Still, obligate aquatic taxa require water, and the most significant threat for the Ash Meadows springs into the future is the further reduction in springflow. Reduction in flow directly influences species needs of “adequate water supply” and free-flowing water,” as well as cascading effects of community structure and physiochemical parameters (Morrison 2013, entire). In consideration of groundwater pumping and climate change, it is reasonable that springflow will change, but some uncertainty exists relative to the magnitude of risk during the next 50 years.

Recent modeling by Halford and Jackson (2020, entire), and Nelson and Jackson (2020, entire) clearly demonstrates that regional groundwater withdrawal at current rates result in lowered water levels and spring discharges (Nelson and Jackson (2020, Fig. 20 B, p. 26). However, some uncertainty exists in the prediction of absolute and interannual variability of water levels due to uncertainty that surrounds the future magnitude and variability of recharge in the system. This uncertainty is further amplified by uncertainty of the impact of climate change on future precipitation, which will affect the magnitude of recharge. Water levels have risen in Devils hole since the 1980s, indicating an increase in recharge, but it is unclear how recharge may affect the system in the future. For example, if there is a future prolonged drought where recharge declines from the current wet period, water levels in Devils Hole (and likely water levels and spring discharges in selected springs in the Ash Meadows NWR) would be expected to decline as a result of groundwater pumping where there is insufficient recharge to replenish the groundwater system (Halford and Jackson 2018).

Overall, the summary table below (Table 7.1) presents estimates of viabilities for the nine species considered here. The viability scores are qualitative, and represent five sequential categories ranging from highest to lowest (i.e., *very high*, *high*, *medium*, *low*, *very low*) based on the 3Rs. As individual populations vary in their 3Rs, their consequent species viability similarly varies in accordance. All spring habitats in this SSA are geographically nearby, but differ considerably in their condition. For species of lower viabilities at present, future reductions in spring flow increase the risk of extirpation and/or extinction in the more extreme scenarios.

Table 7.1. Summary of current and future viabilities for nine endemic springsnails of the Amargosa Valley, Nevada and California. (Potential occurrence: x =species present, o=not present, ?=unknown, dry=spring recorded dry in recent survey)

Site Name	Amargosa tryonia *(Tryonia variegata)*	Ash Meadows pebblesnail *(Pyrgulopsis erythropoma)*	Crystal springsnail *(Pyrgulopsis crystalis)*	Fairbanks springsnail *(Pyrgulopsis fairbankensis)*	Point of Rocks Tryonia *(Tryonia elata)*	Distal-gland springsnail *(Pyrgulopsis nanus)*	Median-gland springsnail *(Pyrgulopsis pisteri)*	Minute tryonia *(Tryonia ericae)*	Sportinggoods tryonia *(Tryonia angulata)*
Kings Pool	x	x							
Point or Rocks	x	x			x				
Big Spring									x
Chalk Spring	dry								
Collins Ranch Spring	x					x			
North of Collins Ranch Spr.	dry					dry		dry	
Crystal Pool			x						x
Fairbanks Spring				x					x
Five Springs	x					x			
Last Chance Spring	o								
Marsh Spring	x						x		
Mary Scott Spring	x					x			
North Indian Spring	x								
South Indian Spring	x								
North Scruggs Spring	x						x	x	
South Scruggs Spring	x								
School Spring	x						x		
South of Clay Pits Spring	Extirpated ?								
Near Crystal Reservoir	?								
Devils Hole	x								
Unnamed Spr., Tecopa, CA	?								
Shoshone Spring, CA	?								
Resiliency	high	high	high	high	moderate	moderate	moderate	moderate	high
Redundancy	high	low	none	none	low	moderate	moderate	low	moderate
Representation	high	very low	none	none	low	moderate	moderate	very low	moderate
Overall Current Viability	**very high**	**High/Mod**	**High/Mod**	**High/Mod**	**Mod**	**Mod**	**Mod**	**Low**	**high**
Future Viability Scenario 1	very high	High/Mod	High/Mod	High/Mod	Mod	Mod	Mod	low	high
Future Viability Scenario 2	high	mod	mod	mod	low	low	low	very low	mod
Future Viability Scenario 3	mod	low	low	low	very low	very low	very low	very low	low

REFERENCES CITED

Abatzoglou J.T. and Brown T.J. 2012. A comparison of statistical downscaling methods suited for wildfire applications, International Journal of Climatology, 32, 772-780.

Abatzoglou, J. T. (2013), Development of gridded surface meteorological data for ecological applications and modelling. International Journal of Climatology , 33: 121–131.

Abele S.L., ed. 2011. Nevada springs conservation plan. The Nature Conservancy, Reno, Nevada. (4 June 2014; www.heritage.nv.gov/sites/default/files/ library/springcons_.pdf)

Al-Bajalan, AR. 2015. To what extent could shale gas "fracking" contaminate ground water. Journal of Petroleum and Environmental Biotechnology 6:1-7.

Archer, S. R., and K. I. Predick. 2008. Climate change and ecosystems of the southwestern United States. Rangelands 30:23-28.

Beever EA, O'Leary J, Mengelt C, West JM, Julius S, Green N, Magness D, Petes L, Stein B, Nicotra AB, Hellmann JJ. 2016. Improving conservation outcomes with a new paradigm for understanding species' fundamental and realized adaptive capacity. Conservation Letters 9:131-137.

Belcher, W.R., and Sweetkind, D.S., eds., 2010, Death Valley regional ground-water flow system, Nevada and California—Hydrogeologic framework and transient ground-water flow model: U.S. Geological Survey Professional Paper 1711, 398 p., https://doi.org/10.3133/pp1711.

Bredehoeft, J.D. 2011. Monitoring regional groundwater extraction: the problem. Ground Water 49(6), pp. 808-814.

Brown K.M., B. Lang, and K.E. Perez. 2008. The conservation ecology of North American pleurocerid and hydrobiid gastropods. Journal of North American Benthological Society 27:484–495.

Brown, K. M., and C. Lydeard. 2010. Mollusca: Gastropoda. Pages 277–306 in J. H. Thorp and A. Covich, editors. Ecology and Classification of North American Freshwater Invertebrates. Third Edit. Academic Press, San Diego, CA.

Burbey, T.J. 1995. Pumpage and Water-level change in the principal aquifer of the Las Vegas Valley, Nevada, 1980–90. Nevada Department of Conservation and Natural Resources. Division of Water Resources Information Report 34. 35 pp. plus tables.

Burch, J. B. 1982. Keys to the Freshwater Gastropods of North America. Pages 217 - 365 in:

Freshwater Snails (Mollusca: Gastropoda) of North America. Environmental Monitoring and Support Laboratory, Office of Research and Development, US Environmental Protection Agency.

Burch, J. B. 1989. North American freshwater snails: introduction systematics, nomenclature, identification, morphology, habitats, distribution. Walkerana 2:1–80. Malacological Publications.

Bureau of Land Management (BLM).1998. Las Vegas resource management plan and final environmental impact statement. Las Vegas Field Office. Las Vegas, Nevada. 52 pp.

Bureau of Land Management (BLM). 2007. Final vegetation treatments using herbicides on Bureau of Land Management Lands in 17 western states programmatic environmental impact statement. 1,650 pp.

Bureau of Land Management (BLM). 2008. BLM Manual 6840 - Special Status Species Management. Release 6-125. December 12, 2008. 48 pp.

Bureau of Land Management (BLM). 2012. Bureau of Land Management Manual 6330 – Management of BLM Wilderness Study Areas. July 13, 2012. 56 pp.

Bureau of Land Management (BLM). 2018. 2017 Final BLM Nevada sensitive and special species status list. Department of the Interior, Bureau of Land Management. BLM IM-NV-2018-003.

California Department of Water Resources. 2016. California Groundwater: Working toward sustainability. Bulletin 118 Interim Update 2016.

Call, R. E., and H. A. Pilsbry. 1886. On *Pyrgulopsis*: a new genus of Rissoid mollusk, with descriptions of two new forms. Proceedings of the Davenport Academy of Natural Sciences 5:9–14.

Chen, Z., S. E. Grasby, and K. G. Osadetz. 2002. Predicting average annual groundwater levels from climatic variables: an empirical model. Journal of Hydrology 260:102–117.

Climate Wizard. 2012. Frequently asked questions. Accessed August 2020, from http://www.climatewizard.org/FAQ.html.

Coles-Ritchie, M., S.J. Solem, A.E. Springer, and B. Pendleton. 2014. Framework for springs stewardship program and proposed action development: Spring Mountains National Recreation Area, Humboldt-Toiyabe National Forest. General technical report RMRS-GTR-330. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 63 pp.

Crandall KA, Bininda-Emonds OR, Mace GM, Wayne RK. 2000. Considering evolutionary processes in conservation biology. Trends in Ecology & Evolution 15:290-295.

Crews, S.C. and L.E. Stevens. 2009. Spiders of Ash Meadows national wildlife refuge, Nevada. The Southwestern Naturalist, 54:331-340.

Deacon, J. E. and W.L. Minckley. 1974. Desert fishes. Desert Biology 2: 385-488.

Deacon, J.E. and C.D. Williams, 1991. Ash Meadows and the legacy of the Devils Hole pupfish. Battle against extinction: native fish management in the American West, pp.69-87.

Deacon, J.E., T.B. Hardy, J. Landye, J. Pollard, W. Taylor, and P. Greger. 1980. Environmental analysis of four aquatic habitats in east-central Nevada June-July, 1980. Interim Summary Report to HDR Sciences. Environmental Consultants, Inc. Las Vegas, Nevada. 236 pp.

Deacon, J. E., A. E. Williams, C. D. Williams, and J. E. Williams. 2007. Fueling population growth in Las Vegas: how large-scale groundwater withdrawal could burn regional biodiversity. BioScience 57:688-698.

Dillon Jr R.T. 2006. Chapter 21. Freshwater gastropoda. Pp. 251–259 in C.F. Strum, T.A. Pearce, and Á. Valdes eds. Mollusks a Guide to their study, Collect Preserv. American Malacological Society, Pittsburgh, Pennsylvania.

Dudley, W.W. Jr. and J.D. Larson. 1976. Effect of irrigation pumping on desert pupfish habitats in Ash Meadows, Nye County, Nevada. Geological Survey Professional Paper 927. 52 pp.

Eakin, T.E. 1963. Ground-water appraisal of Pahranagat and Pahroc Valleys, Lincoln and Nye Counties, Nevada. Ground-Water Resources - Reconnaissance Series Report 21, Department of Conservation and Natural Resources, State of Nevada prepared cooperatively by the Geological Survey, U.S. Department of Interior, Carson City, NV.

Fleishman, E., D.D. Murphy, and D.W. Sada. 2006. Effects of environmental heterogeneity and disturbance on the native and non-native flora of desert springs. Biological invasions 8: 1091–1101.

Furniss, M.J., T.D. Roelofs, and C.S. Yee. 1991. Road construction and maintenance. American Fisheries Society special publication 19:297-323.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. 2013. Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC: Island Press. 506 pp.

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom. 2014. Ch. 20: Southwest. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 462-486. doi:10.7930/J08G8HMN.

Girvetz, E. H., C. Zganjar, G. T. Raber, E. P. Maurer, P. Kareiva, and J. J. Lawler. 2009. Applied Climate-Change Analysis: The Climate Wizard Tool. PLoS ONE 4(12): e8320. doi:10.1371/journal.pone.0008320

Green, T.R., M. Taniguchi, H. Kooi, J. J. Gurdak, D. M. Allen, K. M. Hiscock, H. Treidel, and A. Aureli. 2011. Beneath the surface of global change: Impacts of climate change on groundwater. Journal of Hydrology 405:532-560.

Gurdak, J.J., and C. D. Roe. 2010. Review: recharge rates and chemistry beneath playas of the High Plains aquifer, USA. Journal of Hydrogeology 18:1747–1772.

Halford, K.J., and Jackson, T.R. 2020. Groundwater characterization and effects of pumping in the Death Valley regional groundwater flow system, Nevada and California, with special reference to Devils Hole: U.S. Geological Survey Professional Paper 1863, 178 p., https://doi.org/10.3133/pp1863.

Harrill, J. R. 1986. Groundwater Storage Depletion in Pahrump Valley, Nevada–California, 1962–75. Reston (VA): US Geological Survey. US Geological Survey Water Supply Paper 2279.

Hayford, B.L., J.E. Sublette, and S.J. Herrmann. 1995. Distribution of Chironomids (Diptera: Chironomidae) and Ceratopogonids (Diptera: Ceratopogonidae) along a Colorado thermal spring effluent. Journal of the Kansas Entomological Society 68:77-92.

Heath, R.C. 1983. Basic ground-water hydrology. U.S. Geological Survey Water-Supply Paper 2220. 86 pp.

Hegewisch, K.C., Abatzoglou, J.T., Chegwidden,O., and Nijssen, B., Climate Mapper web tool. Climate Toolbox (https://climatetoolbox.org/) accessed on August 2020.

Herrera-Pantoja, M., and K. M. Hiscock. 2008. The effects of climate change on potential groundwater recharge in Great Britain. Hydrological Processes 22:73–86.

Hershler, R. 1989. Springsnails (Gastropoda: Hydrobiidae) of Owens and Amargosa River (exclusive of Ash Meadows) drainages, Death Valley system, California-Nevada. Proceedings of the Biological Society of Washington 102:176–248. National Museum of Natural History.

Hershler, R. 1994. A review of the North American freshwater snail genus *Pyrgulopsis* (Hydrobiidae). Smithsonian Contributions to Zoology 554:1–115.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. Veliger 41:1–132.

Hershler, R. 1999. A systematic review of the hyrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part II. Genera Colligyrus, Eremopyrgus, Fluminicola, Pristinicola, and Tryonia. Veliger 42:306-337.

Hershler, R. 2001. Systematics of the North and Central American aquatic snail genus Tryonia (Rissooidea: Hydrobiidae). Smithsonian Contributions to Zoology 612:1–53.

Hershler R. and J.J. Landye. 1988. Arizona Hydrobiidae (Prosobranchia: Rissoacea). Smithson Contrib to Zool 459:1–63.

Hershler, R. and H-P. Liu. 2008. Ancient vicariance and recent dispersal of springsnails (Hydrobiidae: Pyrgulopsis) in the Death Valley System, California-Nevada. Pages 91-102 . In, M.C. Reheis, R. Hershler, and D.M. Miller (eds.). Late Cenozoic Drainage History of the Southwestern Great Basin and Lower Colorado River Region: Geologic and Biotic Perspectives. The Geological Society of America Special Paper 439.

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. National Operations Center, Bureau of Land Management, U.S. Department of Interior, Denver, Colorado..

Hershler, R., and D. W. Sada. 1987. Springsnails (Gastropoda: Hydrobiidae) of Ash Meadows, Amargosa basin, California-Nevada. Proceedings of the Biological Society of Washington 100:776–843. National Museum of Natural History.

Hershler, R. and D.W. Sada. 2002. Biogeography of Great Basin freshwater snails of the genus Pyrgulopsis. Pages 255 – 276. In, R. Hershler, D.B. Madsen, and D.R. Currey (eds.). Great Basin aquatic systems history. Smithsonian Contributions to Earth Sciences, Number 33.

Hershler, R. and F.G. Thompson. 1987. North American Hydrobiidae (Gastropoda: Rissoacea): redescription and systematic relationships of *Tryonia* Stimpson, 1865 and *Pyrgulopsis* Call and Pilsbry, 1886. Nautilus (Philadelphia) 101:25–32.

Hershler, R., M. Mulvey, and H.-P. Liu. 2005. Genetic variation in the Desert Springsnail (*Tryonia porrecta*): implications for reproductive mode and dispersal. Molecular Ecology 14:1755-1765.

Hershler, Robert, Liu, H.-P., & Bradford, C. 2013. Systematics of a widely distributed western

North American springsnail *Pyrgulopsis micrococcus* (Caenogastropoda, Hydrobiidae), with descriptions of three new congeners. *ZooKeys*, *330*(0), 27–52.

Hershler, R., H.-P. Liu, and J. Howard. 2014. Springsnails: a new conservation focus in Western North America. Bioscience 64:1-8.

Holman, I.P. 2006. Climate change impacts on groundwater recharge-uncertainty, shortcomings, and the way forward? Journal of Hydrogeology 14:637–647.

Intergovernmental Panel on Climate Change (IPCC). 2014. Summary for policymakers. Pp. 1-32 in: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.

Jaeger, J.R., and R. Rivera. 2015. Relict leopard frog monitoring and management, 2014 Annual Report. Lower Colorado River Multi-Species Conservation Program, Boulder City, Nevada.

Jaeger, K.L., J.D. Olden, and N.A. Pelland. 2014. Climate change poised to threaten hydrologic connectivity and endemic fishes in dryland streams. Proceedings of the National Academy of Sciences 111:13894-13899.

Johnson, P. D., A. E. Bogan, K. M. Brown, N. M. Burkhead, J. R. Cordeiro, J. T. Garner, P. D. Hartfield, D. A. W. Lepitzki, G. L. Mackie, E. Pip, T. A. Tarpley, J. S. Tiemann, N. V Whelan, and E. E. Strong. 2013. Conservation status of freshwater gastropods of Canada and the United States. Fisheries 38:247–282.

Jyrkama, M.I., and J. F. Sykes. 2007. The impact of climate change on spatially varying groundwater recharge in the grand river watershed (Ontario). Journal of Hydrology 338:237–250.

Kabat A.R. and R. Hershler. 1993. The prosobranch snail family Hydrobiidae (Gastropoda: Rissooidea): review of classification and supraspecific taxa. Smithson Contrib to Zool 547:1–94.

Kallstrom, C., M. Burroughs, and J. Jaeger. 2017. Blue Point Spring March 16, 2017 Field Visit Notes. April 2017. 6 pp.

Kilburn, S. 2012. Impacts of introduced crayfish on Ash Meadows aquatic communities: Ash Meadows National Wildlife Refuge, Nevada. Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Natural Resources and Environmental Sciences in the Graduate College of the University of Illinois at Urbana-Champaign. Urbana, Illinois. 68 pp.

Kundzewicz, Z.W., L. J. Mata, N. W. Arnell, P. Doll, P. Kabat, B. Jimenez, K. A. Miller, T. Oki, Z. Sen, and I. A. Shiklomanov. 2008. The implications of projected climate change for freshwater resources and their management. Hydrological Sciences Journal 53:3-10.

Liu, H-P and Hershler, R. 2005. Molecular systematics and radiation of western North American nymphophiline gastropods. Molecular Phylogenetics and Evolution 34:284–298.

Lysne, S.J., L.A. Riley, and W.H. Clark. 2007. The life history, ecology, and distribution of the Jackson Lake springsnail (*Pyrgulopsis robusta* Walker 1908). Journal of Freshwater Ecology 22:647–653.

Lysne, S.J., K.E. Perez, K.M. Brown, R. L. Minton, and J.D. Sides. 2008. A review of freshwater gastropod conservation: challenges and opportunities. Journal of the North American Benthological Society 27:463–470.

Mangal M, Tier C. 1993. A simple direct method for finding persistence times of populations and application to conservation problems. Proceedings of the National Academy of Sciences of the USA 90:1083-1086.

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 D.M. Thome. 2006. Habitat usage by the Page springsnail, *Pyrgulopsis morrisoni* (Gastropoda: Hydrobiidae), from Central Arizona. Veliger 48:8–16.

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.

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 habitat partitioning of habitat by an imperiled springsnail (Hydrobiidae) and a cosmopolitan pond snail (Physidae). Southwestern Naturalist 56:216-223.

Mehany, M.S.H.M. and A. Guggemos. 2015. A literature survey of the fracking economic and environmental implications in the United States. Procedia Engineering 118:169-176.

Mehler, K. and K. Acharya. 2014. Size distribution and nutrient excretion of *Melanoides tuberculata* in a southern Nevada spring ecosystem. Western North American Naturalist 74:386–395.

Mehler, K., K. Acharya, D.W. Sada, and Z. Yu. 2015. Spatial and temporal pattern in length-mass regressions of freshwater gastropods in Nevada spring ecosystems. Malacologia 58:167-177.

Mehlhop, P., and C. C. Vaughn. 1994. Threats to and sustainability of ecosystems for freshwater mollusks. Pages 68-77 in W. Covington and L. F. Dehanid, editors. Sustainable ecological systems: implementing an ecological approach to land management. General technical report Rm-247. U.S. Forest Service, Rocky Mountain Range and Forest Experimental Station, Fort Collins, Colorado.

Mladenka, G.C. 1992. The ecological life history of the Bruneau Hot Springs snail *Pyrgulopsis bruneauensis*. Final Report. Stream Ecology Center. Department of Biological Sciences. Idaho State University. May 1992.

Mladenka G.C. and G.W. Minshall. 2001. Variation in the life history and abundance of three populations of Bruneau hot springsnails (Pyrgulopsis bruneauensis). Western North American Naturalist 61:204–212.Moret, G.J., C.C. Caudill, and M.L. Levandowski. 2014. Mojave Desert Network inventory and monitoring selected large springs pilot study: Saratoga Spring springsnail and benthic macroinvertebrate data. Natural Resource Data Series NPS/MOJN/NRDS—2014/656. National Park Service, Fort Collins, Colorado.

Morrison, R.R., M.C. Stone, and D.W. Sada. 2013. Environmental response of a desert springbrook to incremental discharge reduction, Death Valley National Park, California, USA. Journal of Arid Environments 99:5–13.

Moyle, P.B., R. M. Quiñones, J. V. Katz and J. Weaver. 2015. Fish Species of Special Concern in California. Sacramento: California Department of Fish and Wildlife. www.wildlife.ca.gov.

National Park Service. 2006. National Park Service Policy and the Directives System (https://www.nps.gov/policy/DOrders/thingstoknow.htm). Accessed February 1, 2017.

Nevada Department of Conservation and Natural Resources (DCNR). 2017. Nevada water law 101. Retrieved from http://dcnr.nv.gov/documents/documents/nevada-water-law-101/.

Nevada Division of Water Planning (NDWP). 1999. Nevada State Water Plan. Nevada Department of Conservation and Natural Resources. 959 pp.

Nevada Division of Water Resources. 2008. Order 1197. Nevada State Engineer, Department of Water Resources, Carson City, Nevada. Online at: http://images.water.nv.gov/images/Orders/1197o.pdf; accessed on 9/30/20. 2 pp.

Nevada Division of Water Resources. 2017. Accessed January 31, 2017, from http://water.nv.gov/mapping/hydrographic.cfm.

Nevada Division of Water Resources. 2018. Order 1197A. Nevada State Engineer, Department of Water Resources, Carson City, Nevada. Online at: http://images.water.nv.gov/images/Orders/1197Ao.pdf; accessed on 9/30/20. 2 pp.

Nevada Division of Water Resources. 2019. Amagosa Desert Hydrographic Basin 14-230, Groundwater Pumpage Inventory, Water Year 2019. Department of Conservation and Natural Resources, Carson City, Nevada. 114 pp.

Nicotra, AB, Beever EA, Robertson AL, Hofmann GE, O'Leary J. 2015. Assessing the components of adaptive capacity to improve conservation and management efforts under global change. Conservation Biology 29:1268-1278. O'Brien, C. and D.W. Blinn. 1999. The endemic spring snail *Pyrgulopsis montezumensis* in a high CO_2 environment: importance of extreme chemical habitats as refugia. Freshwater Biology 42:225-234.

O'Brien, C. and D.W. Blinn. 1999. The endemic spring snail *Pyrgulopsis montezumensis* in a high CO_2 environment: importance of extreme chemical habitats as refugia. Freshwater Biology 42:225-234.

Patten, D.T., L. Rouse, and J.C. Stromberg. 2008. Isolated spring wetlands in the Great Basin and Mojave Deserts, USA: potential response of vegetation to groundwater withdrawal. Environmental Management 41:398-413.

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. 1953. Gastropoda (snails, limpets). In Fresh-water Invertebrates of the United States. The Ronald Press Company. New York. pp. 667–693.

Pilsbry, H. A. 1892. Preliminary notices of new forms of fresh-water mollusks. The Nautilus 5:142–143.

Pohlman, K.F., D.J. Campagna, J. B. Chapman, and S. Earman. 1998. Investigation of the origin of springs in the Lake Mead National Recreation Area. Publication No. 41161. Prepared by Water Resources Center, Desert Research Institute, University and Community College System of Nevada. Prepared for National Park Service, Water Resources Division.

Pyron and Brown, 2015. Intro to Mollusca and the class Gastropoda. Pages 381-421 *in* Ecology and General Biology, Fourth Edition.

Raisanen, C. 1991. Status Survey of Four Invertebrates of the Page/bubbling/lolomai Springs/Oak Creek Complex. A report prepared for U.S. Fish and Wildlife Service, Phoenix, Arizona. Yavapai College, Clarkdale, Arizona.

Redford, K.H., Amato, G., Baillie, J., Beldomenico, P., Bennett, E.L., Clum, N., Cook, R., Fonseca, G., Hedges, S., Launay, F. and Lieberman, S., 2011. What does it mean to successfully conserve a (vertebrate) species? BioScience 61:39-48.

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

Sada, D.W. 2008. Synecology of a springsnail (Prosobranchia: Family Hydrobiidae) assemblage in a western U.S. thermal spring province. Veliger 50:59-71.

Sada, D.W. 2009. A guide to springsnail (Family Hydrobiidae) identification and monitoring. Desert Research Institute. Reno, Nevada. 16 pp. plus appendices.

Sada, D.W. 2020. Springs database. Unpublished data for the Ash Meadows area. Desert Research Institute, Reno, Nevada.

Sada, D.W. 2017. Environmental and biological factors influencing Great Basin and surrounding areas springsnail (Family Hydrobiidae) abundance and distribution. 33 pp. plus appendices.

Sada, D.W., and J.E. Deacon. 1994. The probable effects of ground water use proposed by the Las Vegas Valley Water District on spring-dwelling animals in southern Nevada and southeastern California. Unpublished report. February 1, 1994. 36 pp.

Sada, D.W. and K.F. Pohlmann. 2002. Spring inventory and monitoring protocols. Conference proceedings. Spring-fed wetlands: important scientific and cultural resources of the Intermountain Region. http://www.wetlands.dri.edu.

Sada, D.W. and K.F. Pohlmann. 2006. Draft U.S. NPS Mojave Inventory and Monitoring Network. Spring Survey Protocols: Level I and Level II. Desert Research Institute. Reno and Las Vegas, Nevada.

Sada, D.W. and G.L. Vinyard. 2002. Anthropogenic changes in biogeography of Great Basin aquatic biota. Pages 277-293 in R. Hershler, D.B. Madsen, and D.R. Currey, editors. Great Basin aquatic systems history. Smithsonian Institution Press, Washington, D.C.

Sada, D.W. and D.B. Herbst. 2006. Ecology of aquatic macroinvertebrates in Travertine and Nevares Springs, Death Valley National Park, California, with an examination of water diversion effects on their abundance and community structure. Desert Research Institute, Reno, Nevada and University of California, Sierra Nevada Aquatic Research Laboratory, Mammoth Lakes, California. 58 pp. plus appendices.

Sada, D.W. and T. Mihevc. 2011. Grapevive Spring water budget and springsnail and ecosystem study. Unpublished report. BLM serial number N-85375. January 31, 2011. 31 pp.

Sada, D.W. and D.J. Cooper. 2012. Furnace Creek springs restoration and adaptive management plan, Death Valley National Park, California. Desert Research Institute, Reno, Nevada and Department of Forest and Rangeland Stewardship, Colorado State University, Fort Collins, Colorado. Prepared for U.S. National Park Service, Death Valley National Park, Death Valley, California. 59 pp.

Sada, D.W. and C. Rosamond. 2013. Distribution, abundance, and habitat use of the elongate Mud Meadow springsnail (*Pyrgulopsis notidicola*), a species endemic to Soldier Meadow, Humboldt County, Nevada. 24 pp. plus appendices.

Sada, D.W. and A.D. Lutz. 2016. Environmental characteristics of Great Basin and Mojave Desert spring systems. Desert Research Institute, Division of Hydrologic Sciences. 29 pp. plus appendices.

Sada, D.W., K. Acharya, and K. Mehler. 2015. Quantitative and qualitative assessment of the ecological health of Nevada's desert spring ecosystems. Desert Research Institute. 53 pp. plus appendices.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Liu, G. Vecchi, H. Huang, N. Harnik, A. Leetma, N. Lau, C. Li, J. Velez, and N. Naik. 2007. Model projections of an imminent transition to a more arid climate in Southwestern North America. Science 316:1181-1184.

Sgro, C.M, A.J. Lowe, A.A Hoffmann. 2011. Building evolutionary resilience for conserving biodiversity under climate change. Evolutionary Applications 4:326-337.

Sheldon, S.P. 1987. The effects of herbivorous snails on submerged macrophyte communities in Minnesota Lakes. Ecology 68:1920-1931.

Sovacool, B.K. 2014. Cornucopia or curse? Reviewing the costs and benefits of shale gas hydraulic fracturing (fracking). Renewable and Sustainable Energy Reviews 37:249-264.

Springsnail Conservation Team. 2020.Conservation Strategy for Springsnails in Nevada and Utah, Version 1.0. Nevada Department of Wildlife, Reno, and Utah Division of Wildlife Resources, Salt Lake City.

Springer, A.E. and L.E. Stevens. 2009. Spheres of discharge of springs. Hydrogeology Journal, 17(1), pp.83-93.

Stevens, L.E., E.R. Schenk and A.E. Springer. 2020. Springs ecosystem classification. Ecological Applications, p.e2218.

Stillings, L.L. 2011. The source of water for Nevada's Ash Meadows springs. American Currents. Spring (Apr.) 2011. Available online at: http://www.nanfa.org/ac/ash-meadowssprings.pdf (accessed 18 Oct 2020).

Stimpson, W. 1865. Diagnoses of newly discovered genera of gastropods belonging to the sub-fam. Hydrobiinae, of the Family Rissoidae. American Journal of Conchology 1:52–54.

Taylor, D. 1987. Fresh-water molluscs from New Mexico and vicinity. Bulletin 116. New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology. 50 pp.

Troschel, F. H. 1857. Das Gebiss der Schnecken zur begründung einer natürlichen Classification. Volume 1.

Tryon, G. W. J. 1866. Review and Summary of Conchological Publications. "Researches upon Hydrobiinae and allied forms" by Dr. WM. Stimpson. American Journal of Conchology 2:152–158.

Unmack, P.J. and W.L. Minckley. 2008. The Demise of Desert Springs. Chapter 2 in L.E. Stevens and V.J. Meretsky, eds. Aridland springs in North America, ecology and conservation. The University of Arizona Press.

[Service] U.S. Fish and Wildlife Service. 2002. 620 FW 1 Policy, Habitat Management Plans. Division of Conservation Planning and Policy.

[Service] U.S. Fish and Wildlife Service. 2006. Integrated Pest Management Plan for Ash Meadows National Wildlife Refuge. Ash Meadows National Wildllife Refuge and the Southern Nevada Field Office, Las Vegas, Nevada. 152 pp.

[Service] U.S. Fish and Wildlife Service. 2009. Desert National Wildlife Refuge Complex: Ash Meadows, Desert, Moapa Valley, and Pahranagat National Wildlife Refuges: final comprehensive conservation plan and environmental impact statement. Pacific Southwest Region Office. Sacramento, California.

[Service] U.S. Fish and Wildlife Service. 2016. U.S. Fish and Wildlife Service Species Status Assessment Framework: an integrated analytical framework for conservation. Version 3.4 dated August 2016. 21 pp.

[Service] U.S. Fish and Wildlife Service. 2020. The 3Rs defined.

[USGCRP] U.S. Global Change Research Program. 2009. Global climate change impacts in the United States. Karl, T.R., J. M. Melillo, and T. C. Peterson (eds.). United States Global Change Research Program. Cambridge University Press, New York, New York, USA. 188 pp.

[USGCRP] U.S. Global Change Research Program. 2014. Georgakakos, A., P. Fleming, M. Dettinger, C. Peters-Lidard, Terese (T.C.) Richmond, K. Reckhow, K. White, and D. Yates, 2014: Ch. 3: Water resources. Climate change impacts in the United States: the third national climate assessment, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, pp. 69-112.

United States Federal Government. 2014: U.S. Climate Resilience Toolkit. [Online] http://toolkit.climate.gov. Accessed [August 2020].

van der Kamp, G. 1995. The hydrogeology of springs in relation to the biodiversity of spring fauna: a review. Journal of the Kansas Entomological Society 68:4–17.

Vu, B., M. Chen, R.J. Crawford, and E.P. Ivanova. 2009. Bacterial extracellular polysaccharides involved in biofilm formation. Molecules 14:2,535–2,554.

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. 2014. Ch. 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. *doi:10.7930/J0KW5CXT*.

Weissinger, R.H., D.W. Perkins, and E.C. Dinger. 2012. Biodiversity, water chemistry, physical characteristics, and anthropogenic disturbance gradients of sandstone springs on the Colorado Plateau. Western North American Naturalist 72:393–406.

Weissinger, R., T. E. Philippi, & D. Thoma, D. 2016. Linking climate to changing discharge at springs in Arches National Park, Utah, USA. Ecosphere 7(10).

Welden, F.W. 2003. History of water law in Nevada and the western states. Background paper 03-2. Nevada Legislative Counsel Bureau Research Division. 15 pp.

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.

Wildlife Action Plan Team. 2012. Nevada Wildlife Action Plan. Nevada Department of Wildlife, Reno. *www.ndow.org/Nevada_Wildlife/Conservation/Nevada_Wildlife_Action_Plan*.

Wyckoff, B., and M. Floyd. 2016. California's groundwater: Working toward sustainability (Bulletin 118, Interim Update 2016). Sacramento, California.

Zackay, A. 2007. Random genetic drift and gene fixation. [online] https://www.metabolic-economics.de/pages/seminar_theoretische_biologie_2007/ausarbeitungen/zackay.pdf [Accessed 21 June 2018].

Personal Communications or *In Litteris*

Lange, C. 2020. Request for review of a draft species status assessment for nine Nevada springsnails. Email response. November 2020.

Lee, C. 2017. Renovation planning for Big Spring, Ash Meadows NWR. Email correspondence. March 2017.

Parmenter, S. 2020. Request for review of a draft species status assessment for nine Nevada springsnails. Email response. November 2020.

Wilson, K. 2020. Request for review of a draft species status assessment for the nine Nevada springsnails. Electronic response. November 2020.

APPENDIX A: Current Management and Conservation Measures
The springsnails described in this assessment occur on private, State, and Federal lands. Various laws, regulations, policies, and management plans may provide conservation or protections for springsnails. Particularly relevant ones include the following:

Federal Laws, Regulations, Policies, and Management Plans

National Environmental Policy Act of 1969
All Federal agencies are required to adhere to the National Environmental Policy Act of 1969 (NEPA; 42 U.S.C. 4321 et seq.) for projects they fund, authorize, or carry out. Prior to implementation of such projects with a Federal nexus, NEPA requires the agency to analyze the project for potential impacts to the human environment, including natural resources. The Council on Environmental Quality's regulations for implementing NEPA state that agencies shall include a discussion on the environmental impacts of the various project alternatives (including the proposed action), any adverse environmental effects that cannot be avoided, and any irreversible or irretrievable commitments of resources involved (40 CFR part 1502). The public notice provisions of NEPA provide an opportunity for the Service and other interested parties to review proposed actions and provide recommendations to the implementing agency. NEPA does not impose substantive environmental obligations on Federal agencies—it merely prohibits an uninformed agency action. However, if an Environmental Impact Statement is prepared for an agency action, the agency must take a "hard look" at the consequences of this action and must consider all potentially significant environmental impacts.

Although NEPA requires full evaluation and disclosure of information regarding the effects of contemplated Federal actions on sensitive species and their habitats, it does not by itself regulate activities that might affect the nine springsnails evaluated herein; that is, effects to the species and their habitat would receive the same scrutiny as other plant and wildlife resources during the NEPA process and associated analyses of a project's potential impacts to the human environment. We receive notification letters for Draft and Final Environmental Impact Reports prepared pursuant to NEPA including Land Management Plans, as discussed below. The BLM follows the NEPA process and analysis for projects planned and implemented on their lands.

Bureau of Land Management
Land management by the BLM is directed by the following laws, policies, manuals, and management plans. These directives provide conservation assurance to springsnails as stated in the following:

Federal Land Policy and Management Act of 1976
The Federal Land Policy and Management Act of 1976 (FLPMA; 43 U.S.C. 1701 *et seq.*) is the primary Federal law governing most land uses on BLM lands, and directs development and implementation of Resource Management Plans (RMPs) that direct management at a local level. All nine Nevada springsnails considered here (Amargosa Tryonia (*Tryonia variegata*), Crystal springsnail (*Pyrgulopsis crystalis*), distal-gland springsnail (*Pyrgulopsis nanus*), Fairbanks

springsnail (*Pyrgulopsis fairbankensis*), median-gland springsnail (*Pyrgulopsis pisteri*), minute tryonia (*Tryonia ericae*), Point of Rocks tryonia (*Tryonia elata*), sportinggoods tryonia (*Tryonia angulata*) have been designated as sensitive species in 2018 by the BLM lands in Nevada (BLM IM-NV-2018-003). According to present taxonomy, only one species, Amargosa Tryonia, is known to occur outside of lands managed by the Service, and may likely occur elsewhere. Further, BLM policies direct management to consider candidate species on public lands under their jurisdiction. The management guidance afforded species of concern and candidate species under BLM Manual 6840 – Special Status Species Management (BLM 2008) states that "Bureau sensitive species will be managed consistent with species and habitat management objectives in land use and implementation plans to promote their conservation and to minimize the likelihood and need for listing under the Endangered Species Act" (BLM 2008, p. .05V). BLM Manual 6840 further requires that RMPs should address sensitive species, and that implementation "should consider all site-specific methods and procedures needed to bring species and their habitats to the condition under which management under the Bureau sensitive species policies would no longer be necessary" (BLM 2008, p. 2A1).

RMPs are the basis for all actions and authorizations involving BLM-administered lands and resources. They authorize and establish allowable resource uses, resource condition goals and objectives to be attained, program constraints, general management practices needed to attain the goals and objectives, general implementation sequences, intervals and standards for monitoring and evaluating RMPs to determine effectiveness, and the need for amendment or revision (43 CFR 1601.0-5(k)). The RMPs also provide a framework and programmatic direction for implementation plans, which are site-specific plans written to regulate decisions made in a RMP. Examples include fluid mineral development, travel management, and wildlife habitat management. Implementation plan decisions normally require additional planning and NEPA analysis, as described above.

Three RMPs in the analysis area for this report include springsnail habitat management objectives, each of which contain specific measures or direction pertinent to management of springsnails or their habitat. These measures and their direction vary, with some measures directed at a particular land resource (e.g., riparian areas), and others relevant to specific best management practices (e.g., limited water extraction). If an RMP contains specific direction regarding springsnail habitat, conservation, or management, it represents a regulatory mechanism that has the potential to ensure that the species and its habitats are protected during permitting and other decision-making on BLM lands. This section describes our understanding of how RMPs are currently implemented in relation to springsnail conservation.

Bureau of Land Management Manual 6330 – Management of BLM Wilderness Study Areas

This policy was established in 2012, superseding the Interim Management Policy for Lands Under Wilderness Review issued in 1979. The objectives of this policy are to (1) manage and protect WSAs, consistent with relevant law, to preserve wilderness characteristics so as not to impair the suitability of such areas for designation by Congress as wilderness; and (2) provide policy guidance for prolonged stewardship of WSAs until Congress makes a final determination on the management of WSAs (BLM 2012, page 1-2). The non-impairment standard is defined as uses and/or facilities that are both temporary and do not create surface disturbance (BLM 2012d, page 1-10). This policy provides guidance on evaluating proposals for new uses within WSAs, but also allows certain pre-existing uses to continue (such as grazing, mining, and mineral leasing uses and facilities that were allowed on the date of approval of FLPMA (October 21, 1976).

National Park Service

Organic Act

The NPS was established by the Organic Act of 1916.
The NPS Directives System provides instructions and guidance for required and/or recommended actions that has 3 levels of documents (https://www.nps.gov/policy/DOrders/thingstoknow.htm, Accessed February 1, 2017). The first level is the Management Policies book that provides a framework to guide management decisions (NPS 2006). Level 2 is the Director's Orders, which has more detailed interpretations. Level 3 includes reference manuals, handbooks, and other documents having further detailed information. All policies and direction are "guided by and consistent with the Constitution, public laws, Executive proclamations and orders, and regulations and directives from higher authorities".
The management policies (Level 1) are mandatory for NPS unless specifically waived by the Secretary, Assistant Secretary, or Director (NPS 2006, p. 3). Much of the management policy applicable to springsnails and the springs they depend on are found within the Natural Resource Management Section (NPS 2006, pp. 35–57). There are many policies that may benefit springsnails directly or indirectly but the following from pages 42–44 are particularly relevant to springsnail conservation, and may provide benefits to the springsnails on NPS lands:

- "preserving and restoring the natural abundances, diversities, dynamics, distributions, habitats, and behaviors of native plant and animal populations and the communities and ecosystems in which they occur;
- restoring native plant and animal populations in parks when they have been extirpated by past human-caused actions;
- minimizing human impacts on native plants, animals, populations, communities, and ecosystems, and the processes that sustain them; and
- prevent the introduction of exotic species into units of the national park system, and remove, when possible, or otherwise contain individuals or populations of these species that have already become established in parks."

In addition the NPS generally relies upon natural processes to maintain animal species and their natural fluctuations; however management may be permitted in unnatural conditions where it won't cause other unacceptable impacts (NPS 2006, p. 44)

The Director's Order 77 and Natural Resources Management Reference Manual #77 are currently being developed and are likely to have guidance or direction that benefit springsnail conservation (https://home.nps.gov/applications/npspolicy/DOrders.cfm, Accessed February 1, 2017). The Freshwater Resources Management section of the reference manual provides policy and program objectives "...to maintain, rehabilitate, and perpetuate the inherent integrity of water resources and aquatic ecosystems" (https://www.nature.nps.gov/rm77/freshwater.cfm, Accessed February 1, 2017) that are applicable to spring and springsnail conservation.

Death Valley Management Plan

The NPS established the Death Valley Management Plan
The NPS Directives System provides instructions and guidance as required and/or recommended actions that has 3 levels of documents.

U.S. Fish and Wildlife Service

Land management by the U.S. Fish and Wildlife Service (Service) is directed by the following laws, policies, manuals, and management plans. These directives provide conservation assurance to springsnails as stated in the following:

U.S. Fish and Wildlife Service, National Wildlife Refuge System Administration Act of l966 and the National Wildlife Refuge Improvement Act, 1997

The National Wildlife Refuge System Administration Act of 1966 authorized the Secretary of the Interior to permit the use of refuges whenever it is determined that such a use is compatible with the purposes for which the area was established (Service 2012b, no pagination). The National Wildlife Refuge Improvement Act of 1997 amended the 1966 Act to specifically state that the mission of the National Wildlife Refuge System is wildlife conservation. It identified a number of wildlife-dependent recreational uses that will be given priority consideration, mandated a long-term refuge planning process, and clarified the process for determining the compatibility of refuge uses (Service 2012c, no pagination). It also mandated that all Service refuges have a Comprehensive Conservation Plan by 2012 (Service 2009, p. 1). The National Wildlife Refuge System is managed by the Service primarily for the benefit of fish, wildlife, and plant resources and their habitats (Service 2009, p. 2).

U.S. Fish and Wildlife Service, Desert Refuge Complex Comprehensive Conservation Plan (Ash Meadows, Desert, Moapa Valley, and Pahranagat National Wildlife Refuges), 2009

The Service manages the Desert National Wildlife Refuge Complex in accordance with the approved Comprehensive Conservation Plan (CCP). The CCP provides long-range guidance on refuge management through its vision, goals, objectives, and strategies. The CCP also provides a basis for a long-term adaptive management process that includes monitoring the progress of management actions, evaluating and adjusting management actions based on new information or techniques, and revising management and monitoring plans accordingly. The Amargosa tryonia (*Tryonia variegata*), Ash Meadows springsnail (*Pyrgulopsis erythropoma*), Crystal springsnail (*Pyrgulopsis crystalis*), Distal-gland springsnail (*Pyrgulopsis nanus*), Fairbanks springsnail (*Pyrgulopsis fairbankensis*), Median-gland springsnail (*Pyrgulopsis pisteri*), Minute tryonia (*Tryonia ericae*), Point of Rocks tryonia (*Tryonia elata*), Sportinggoods tryonia (*Tryonia angulata*), all occur on Ash Meadows National Wildlife Refuge.

Goal 1 for Ash Meadows National Wildlife Refuge species management is to restore and maintain viable populations of all endemic, endangered, and threatened species within the refuge's Mojave Desert oasis ecosystem. Strategies to meet this goal include: 1) Investigate feasibility and funding for captive populations of all sensitive species (e.g., aquatic snails, etc.).

U.S. Fish and Wildlife Service, Natural Resource Management Plan Desert Refuge Complex Comprehensive Conservation Plan (Ash Meadows, Desert, Moapa Valley, and Pahranagat National Wildlife Refuges), (in review, 2020)

As a step-down management plan from the CCP above, the Natural Resource Management Plan (NRMP) serves as the Refuge's habitat management plan (U.S. Fish and Wildlife Service 2002). It updates refuge priority resources of concern (ROCs), as well as their status and threats and ultimately identifies priority strategies to achieve the refuge's natural resource conservation vision and purposes given its limited resources. Specifically, it provides specific, results-oriented, and measurable objectives for evaluating conservation progress. It also clearly articulates the optimal set of management strategies the Service should implement over the next 15 years while addressing the potential impacts of climate change expected over the next 50 years. As part of the NRMP effort, a 15-year work plan was also assembled to guide refuge activities. Refuge management strategies and activities, along with measures of progress, maximize the conservation of priority refuge resources in an adaptive framework. Restoring and maintaining viable populations of all endemic, endangered, and threatened species—as stated in the refuge purpose and CCP—remains the focus of refuge management activities. Given the diversity and unique qualities of Ash Meadows ecosystems and species, the considerable threats to their persistence, and limited resources for refuge operations, careful prioritization and selection of the management actions that will have the greatest long-term impact is key. The NRMP is designed to guide refuge staff when making challenging decisions. This plan and its associated databases provide detailed documentation of the current understanding of refuge resources and a flexible framework for the implementation of adaptive management.

State Plans

STATE OF NEVADA

Nevada Department of Wildlife, Nevada State Wildlife Action Plan, 2012

The state of Nevada does not include any invertebrate taxa under their state list of protected species. There are no legal protections provided under Nevada Revised Statute (NRS) 501, and they are not listed in the Nevada Administrative Code (NAC) Chapter 503. They are however, each identified as Species of Concern in Nevada. The state's Department of Conservation and Natural Resources maintains the Nevada Natural Heritage Program (NNHP), which does track the species status of invertebrates. The NNHP recognizes all nine species considered here as critically imperiled, rank *S1* (*Tryonia angulata, T. elata, T. ericae, Pyrgulopsis erythropoma, P. crystalis, P. nanus, P. fairbankensis, P. pisteri*) or imperiled, rank *S2* (*T. variegata*). Ranks of *S2* or *S1* are defined as species with high or very high (respectively) risks of extirpation in the jurisdiction due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors. One species considered here is known to historically occur in California: the regional endemic Amargosa tryonia (*Tryonia variegata*). This species is not protected on the State of California's list of protected invertebrates.

The Nevada Department of Wildlife developed its State Wildlife Action Plan as a requirement to apply for State Wildlife Grant funds through the U.S. Fish and Wildlife Service. These funds are used by Nevada Department of Wildlife for the conservation of Nevada's wildlife. One of the State Wildlife Action Plan's goals is to establish "springs and springbrook habitats functioning naturally within the natural fluctuation inherent to the spring type". Objectives that would need to be met to achieve this goal include the following: (1) a measurable increase in the number of springs and springbrooks functioning naturally and supporting the natural ecological community expected for each spring by 2022; and (2) no net loss of spring/springbrook-dependent Species of Conservation Priority. To assist in meeting these objectives, the Nevada Department of Wildlife and Utah Division of Wildlife Resources initiated a multi-partner planning process to develop a regional Conservation Agreement and Strategy for springsnails throughout the states of Nevada and Utah, discussed further below in 3.2.2.

STATE OF CALIFORNIA

California Department of Fish and Wildlife (CDFW), California State Wildlife Action Plan, 2015

Congress created the State and Tribal Wildlife Grants (SWG) program in 2000, recognizing the need to fund programs for the conservation of wildlife diversity. Congress mandated each state and territory to develop by 2005 a State Wildlife Action Plan (SWAP) that provided a comprehensive wildlife conservation strategy to continue receiving federal funds through the SWG program. California's first SWAP was completed by California Department of Fish and Game (now the California Department of Fish and Wildlife [CDFW]) and approved by the Service in 2005. California's SWAP 2005 identified and targeted Species of Greatest Conservation Need (SGCN) and the vital habitats on which they depend. The SWG program requires SWAP updates at least every 10 years, and CDFW completed SWAP 2015 that guides conservation efforts through 2025.

A key element of the SWAP is identifying and compiling information on the species of wildlife that are indicative of the state's biological diversity and have the greatest need for conservation, identified in the SWAP as species of greatest conservation need. Only one of the 9 springsnail species occur in California, the Amargosa tryonia, and it is not identified as a species of greatest conservation need in the SWAP, nor as species of special concern. All springsnails in the State of California are controlled for collection, importation, and possession Fish and Game Code and Title 14, of the California Code of Regulations.

Other Agreements and Plans within the Analysis Area

U.S. Fish and Wildlife Service Recovery Plans

Recovery Plan for the Endangered and Threatened Species of Ash Meadows, Nevada 1990

The prime objective of the Ash Meadows Recovery Plan is to restore six endangered and six threatened species (Devils Hole pupfish, Warm Springs pupfish, Ash Meadows Amargosa pupfish, Ash Meadows speckled dace, Ash Meadows naucorid, Ash Meadows niterwort, Ash Meadows blazing star, Ash Meadows milkvetch, Ash Meadows sunray, spring-loving centaury, Ash Meadows gumplant, and Ash Meadows ivesia) that occur at Ash Meadows National Wildlife Refuge to non-listed status, and protect 20 candidate species so listing is not necessary, by securing, restoring and protecting viable, self-sustaining populations for the 32 species in the Ash Meadows ecosystem. The 20 candidate species include 10 springsnails: Amargosa tryonia, Ash Meadows pebblesnail, Crystal springsnail, distal-gland springsnail, elongate-gland springsnail, Fairbanks springsnail, median-gland springsnail, minute tryonia, Point of Rocks tryonia, Sportinggoods tryonia.

The recovery plan defines conditions that must be met within essential habitat to conserve these springsnail species:

- All non-native animals and plant species must be eradicated from essential habitat. These non-native species currently include sailfin mollies, mosquitofish, largemouth bass, black bullheads, bullfrogs, crayfish, turban snails, wild horses, salt cedar and Russian olive.
- Secure and protect the Ash Meadows aquifer so that all springflows return to historic discharge rates, and the water level in Devil's Hole is maintained at a minimum level of 1.4 feet below the copper washer.
- Reestablish water to historic springbrook channels which are free of barriers that eliminate genetic exchange between populations by preventing movement of native fishes throughout their historic range.
- The essential habitat must be secure from detrimental human disturbances including mining, off-road vehicles, and introduction of non-native species.
- The listed Ash Meadows naucorid, the two candidate aquatic insects, and 13 candidate snails are present in all the locales that they have historically occupied.

Ash Meadows Natural Resource Management Plan 2019

The Desert NWR developed the Ash Meadows Natural Resource Management Plan (NRMP) in 2019 based on the 2009 Desert NWR Complex Comprehensive Conservation Plan. Complex Comprehensive Conservation Plan broadly described the desired future state of refuge ecosystems and ways that the refuge may achieve the refuge purpose of conservation of endemic species and ecosystems and migratory bird habitat. These goals have been stepped down to the NRMP, a more specific plan to help prioritize management efforts at Ash Meadows NWR, along with an accompanying Inventory and Monitoring Plan (IMP).

The NRMP is an iterative plan, meaning it will be adapted and updated over time as additional information is collected. It provides a framework for annual work planning and reporting, assessing conservation progress (goals/objectives), learning, and adjusting over time. This approach involves 1) identification of natural resource conservation priorities (also known as priority resources of conservation concern or conservation targets), 2) refinement of conservation goals and objectives so that it's crystal clear what conservation success looks like, 3) identification of the highest priority management strategies—those most likely to lead to achievement of stated goals and objectives, 4) identification of the highest priority surveys needed to evaluate progress in achieving goals and objectives, and 5) institution of a regular practice of evaluation, learning, and adaptation through annual work planning and evaluation.

In the NRMP, springsnails are considered a nested target within the desert springs and outflows target. A Nested target is an ecosystem, species, or ecological process that is inherently conserved if the broader target is conserved. The NRMP broadly defines ecosystem targets, identifies and ranks threats to targets, and identifies broad strategies for ameliorating threats. The NRMP identifies climate change, groundwater reduction, legacy habitat alteration, and nuisance species and pathogens as the highest priority threats. The NRMP identifies three strategies for conservation of target resources: provide critical support (monitoring and adaptive management), manage pests, and restore hydrology.

Recovery Plan for the Devils Hole Pupfish, 1980

The primary goal of the Devils Hole Pupfish Recovery Plan is to restore and maintain the Devils Hole pupfish through species and habitat management procedures. The plan provides a list of actions to achieve the primary goal that include law enforcement protection of Devils Hole, monitoring, and restoration. The plan also identifies the need to work with government and private interests to address the threat of groundwater withdrawal.

Of the 11 springsnail species, only Ash Meadows tryonia occurs in Devils Hole. The Devils Hole strategic plan does not address the Ash Meadows tryonia; however, actions identified in the plan to restore and maintain Devils Hole pupfish, such as law enforcement protection of Devils Hole, monitoring, restoration actions, and protection from ground water withdrawal, also have undoubtedly benefitted Ash meadows tryonia.

The 1990 Recovery Plan for the Endangered and Threatened Species of Ash Meadows, Nevada incorporated the tasks and goals of the 1980 Devils Hole Pupfish Recovery Plan and thus takes "precedence in guiding these recovery actions to provide for all components of the ecosystem."

Voluntary and Stipulated Agreements

Conservation Agreement and Strategy for Springsnails in Nevada and Utah (CAS), 2017

The Conservation Agreement for springsnails in Nevada and Utah was developed to assist in the implementation of conservation measures for springsnail species in Nevada, Utah, and adjacent areas as a collaborative and cooperative effort among resource agencies, governments, and landowners. The desired outcome is to ensure the long-term conservation and persistence of springsnails and their associated habitats throughout Nevada and Utah and to contribute to development of range-wide conservation efforts for these species.

The conservation agreement outlines goals and objectives to protect species and their habitats and will be linked to a conservation strategy that includes the actions intended to address the conservation agreement goals and objectives. The Conservation Agreement (Agreement) between multiple agencies, stakeholders, and other interested parties was completed in 2017 and executed in 2018. The corresponding Strategy is being drafted and should be completed by the end of 2019. The CAS has a ten-year duration and covers 98 species including the genera *Pyrgulopsis* (including all six species evaluated in this document)*, Assiminea, Eremopyrgus, Juga, Fluminicola,* and *Tryonia* with the realization that accommodations for taxonomic changes are likely.

The primary goal of this Agreement is to ensure the continued persistence of springsnails and their habitats in Nevada and Utah to preclude ESA listing. The goal will be achieved through implementation of specific objectives listed below and conservation measures identified in the Strategy. The conservation actions described in the Strategy should lead to the protection and enhancement of these unique species and their associated habitats. The status of springsnail species will be evaluated annually by the Springsnail Conservation Team (SCT) through an adaptive management framework to assess program progress.

The following conservation objectives will be implemented to reach the goal of the Agreement. Included with each objective is a statement on how the objective will benefit springsnail species in Nevada and Utah and a standard to determine if the objective was successful at achieving the goal. The conservation actions and commitments by the signatories will be implemented as proposed in the Strategy. To date, Objective 4 is complete and the SCT is actively working on the other objectives.

- Objective 1. Compile known springsnail distribution, status, and habitat data into a single comprehensive and accessible database and incorporate new information as it becomes available to manage extant and future spatial and biological information for springsnail conservation.

- Objective 2. Identify, assess, and reduce known and potential threats to springsnail populations and their associated habitats at occupied sites.
- Objective 3. Maintain, enhance, and restore springsnail habitats in Nevada and Utah to ensure the continued persistence of the species.
- Objective 4. Develop a Springsnail Conservation Team, which will be tasked with development and implementation of the Strategy and coordinating on-the-ground conservation actions for identified springsnail species and habitats.

Objective 5. Create education and outreach tools that generate broad awareness and strong support for the conservation of springsnails and their habitats among landowners, agencies, and the general public.

APPENDIX B: Survey Data and Threat Evaluation for Springs Supporting Nine Springsnails Species in this SSA Report.

Kings Pool:

Appendix B.1a. Historical and current springsnail surveys at Kings Pool.

Spring Province:		Kings Pool at Point of Rocks Spring			
Species recorded:		*Pyrgulopsis erythropoma*		*Tryonia variegata*	
Survey description	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	x		x	
Current springsnail occurrence/density			CPUE		CPUE
USGS	2018	x	C	x	S
FWS/Sada	2020	x	A	x	A
Current habitat conditions					
High quality restored habitat					
Slight visitor traffic					

CPUE: A= abundant, C= common, S=scarce
x= species present
ns= not surveyed

Appendix B.1b: Threats for Kings Pool.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Vegetation and Soil Disturbance (Recreation)	2	1	1	unknown

See methodology (Chapter 2) for explanation of column headings

Point of Rocks spring province:

Appendix B.2a. Historical and current springsnail surveys at Point of Rocks Spring Province.

Spring province:	Point of Rocks springs	
Species recorded:	*Pyrgulopsis erythropoma*	*Tryonia elata*

Survey description	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	x		x	
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	x	C	x	S
Service/Sada (unpubl.)	2020	x	A	x	S

Current Habitat Conditions

High quality restored habitat.
Both genera found overall, but *Tryonia* scarce in some areas.
Restored habitat favors *Pyrgulopsis.*

CPUE: A= abundant, C= common, S=scarce
x = species present
ns= not surveyed

Appendix B.2b: Threats for Point of Rocks Spring Province.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Vegetation and Soil Disturbance (Recreation)	2	1	1	unknown
Spring (channel) Modification	2	1 - 4	1 - 6	unknown

See methodology (Chapter 2) for explanation of column headings.

Big Spring:

Appendix B.3a. Historical and current springsnail surveys at Big Springs.

Spring:		Big Spring	
Species recorded:		*Tryonia angulata*	
Survey description	**year**	***Tryonia***	
Hershler and Sada	1985	x	
Sada (unpubl.)	2008	x	
Current springsnail occurrence/density			CPUE
USGS (unpubl.)	2018	x	C
Service/Sada (unpubl.)	2020	ns	

Current Habitat Conditions

Tryonia common, not abundant.
Water diversion from main channel (irrigation).

CPUE: A= abundant, C= common, S=scarce
x = species present
ns= not surveyed

Appendix B.3b Threats for Big Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Spring Modification (Water Diversion)	2	0	0	unknown
Aquatic predators (invasive species)	2	0	0	unknown

See methodology (Chapter 2) for explanation of column headings.

Chalk Spring:

Appendix B.4a. Historical and current springsnail surveys at Chalk Springs.

Spring:		Chalk Springs			
Species recorded:		*Pyrgulopsis sanchezi (NP)*		*Tryonia variegata*	
Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	ns		ns	
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	Dry	C	Dry	S
Service/Sada (unpubl.)	2020	ns		ns	

Current Habitat Conditions

Spring overgrown.
No visible water.
T. vareigata occurs numerous other places at Ash Meadows NWR.

CPUE: A= abundant, C= common, S=scarce
NP = species not petitioned
x = species present
ns = not surveyed

Appendix B.4b. Threats for Chalk Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Spring Modification (drought/unknown)	2	0	6	5

See methodology (Chapter 2) for explanation of column headings.

Collins Ranch Spring:

Appendix B.5a. Historical and current springsnail surveys at Collins Ranch Spring.

Spring:		Collins Ranch Spring				
Species recorded:		*Pyrgulopsis nanus (NP)*		*Tryonia variegata*		
		Pyrgulopsis licina (NP)				
Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***		
Hershler and Sada	1985	x		x		
Sada (unpubl.)	2008	x		x		
Current springsnail occurrence/density			CPUE		CPUE	
USGS (unpubl.)	2018	x	C	x	S	
Service/Sada (unpubl.)	2020	x	C	x	C	

Current Habitat Conditions

Diffuse source leading to well defined channel that marshes out.
Little bank vegetation (post-fire), but both *Tryonia* and *Pyrgulopsis* common.

CPUE: A= abundant, C= common, S=scarce
NP= species not petitioned
x = species present
ns= not surveyed

Appendix B.5b. Threats for Collins Ranch Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Spring Modification (overgrown vegetation)	1	1	5	0
Vegetation and Soil Disturbance (Recreation)	2	1	5	0

See methodology (Chapter 2) for explanation of column headings.

North of Collins Ranch Spring:

Appendix B.6a. Historical and current springsnail surveys at North of Collins Ranch Springs.

Spring province:	North of Collins Ranch Springs	
Species recorded:	*Pyrgulopsis nanus (NP)*	*Tryonia ericae*
	Pyrgulopsis licina (NP)	*Tryonia variegata*

Survey description	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	0		0	
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	Dry	n/a	Dry	n/a
Service/Sada (unpubl.)	2020	0	n/a	0	n/a

Current Habitat Conditions/Notes

Several point sources were identified and surveyed by USGS and the Service.
USGS (2018) found no water at one spring source, and a small pool at another.
In 2020, the Service similarly found little water, and no springsnails were present.
T. ericae may be gone from this site.

CPUE: A= abundant, C= common, S=scarce

x = species present

NP=Not petitioned

ns= not surveyed

Appendix B.6b. Threats for North of Collins Ranch Springs.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Spring Modification (overgrown vegetation)	2	0	0	0

See methodology (Chapter 2) for explanation of column headings.

Crystal Spring:

Appendix B.7a. Historical and current springsnail surveys at Crystal Spring.

Spring:		Crystal Spring			
Species recorded:		*Pyrgulopsis crystalis*		*Tryonia angulata*	
Survey description	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	x		x	
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	x	S	x	A
Service/Sada (unpubl.)	2020	0		x	A

Current Habitat Conditions/Notes

High quality restored habitat by AMNWR
invasive fish/crayfish/red-rimmed melania
Only one *Pyrgulopsis* not found in 2018 USGS surveys, but snorkel/scuba divers required.
Pyrgulopsis restricted to the spring source, ~ 5 m (16 ft) below surface.
Only known occurrence for *P. crsytalis.*

CPUE: A= abundant, C= common, S=scarce
x = species present
NP = not petitioned
ns= not surveyed

Appendix B.7b. Threats for Crystal Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Vegetation and Soil Disturbance (Recreation)	2	1	4	1
Aquatic Predation (invasive species)	2	1	4	1
Aquatic Competition (invasive species)	2	1	4	1

See methodology (Chapter 2) for explanation of column headings.

Fairbanks Spring:

Appendix B.8a. Historical and current springsnail surveys at Fairbanks Spring.

Spring:		Fairbanks Spring			
Species recorded:		*Pyrgulopsis fairbankensis*		*Tryonia angulata*	
Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	ns		ns	
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	x	A	x	S
Service/Sada (unpubl.)	2020	x	C	x	C

Current Habitat Conditions/Notes

Heavily modified spring and outflow many years prior.

Spring and outflow are completely stable/ naturalized.

Invasive fishes and red-rimmed melania

CPUE: A= abundant, C= common, S=scarce
x = species present
NP = not petitioned
ns= not surveyed

Appendix B.8b. Threats for Fairbanks Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Spring Modifications (Water Diversion)	2	0	0	0
Aquatic competition (invasive species)	2	0	0	0
Aquatic Predation (invasive species)	2	0	0	0

See methodology (Chapter 2) for explanation of column headings.

Five Springs province:

Appendix B.9a. Historical and current springsnail surveys at Five Springs province.

Spring province:		Five Springs			
Species recorded:		*Pyrgulopsis nanus (NP)*		*Tryonia variegata*	
Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	x		ns	
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	x	C	x	C
Service/Sada (unpubl.)	2020	x	C	x	C

Current Habitat Conditions/Notes

Several sources are combined to form single channel, historically modified
Pyrgs abundant all sources, Tryonia occurs sporadically.
All springs geographically close, comprise a single population unit.
Invasive red-rimmed melania

CPUE: A= abundant, C= common, S=scarce
x = species present
NP = not petitioned
ns= not surveyed

Appendix B.9b. Threats for Five Springs province.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Aquatic competition (invasive species)	2	0	0	0

See methodology (Chapter 2) for explanation of column headings.

Last Chance Spring:

Appendix B.10a. Historical and current springsnail surveys at Last Chance Spring.

Spring:	Last Chance Spring			
Species recorded:	*Pyrgulopsis licina (NP)*			*Tryonia variegata*

Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***
Hershler and Sada	1985	x		x
Sada (unpubl.)	2008	x		0

Current springsnail occurrence/density			CPUE	CPUE
USGS (unpubl.)	2018	Dry		Dry
Service/Sada (unpubl.)	2020	x	A	0

Current Habitat Conditions/Notes
Service 2020: Open water pooled on south side of spring box, and extended west > 50 m (164 ft).
Extremely dense emergent/terrestrial vegetation at source.
Native herbivores use spring extensively.
Old concrete spring box no longer in use

CPUE: A= abundant, C= common, S=scarce
x = species present
NP = not petitioned
ns= not surveyed

Appendix B.10b. Threats for Last Chance Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Spring Modification (overgrown vegetation)	2	4	3	0
Vegetation and Soil Disturbance (Ungulate Use/Trampling)	2	3	2	3

See methodology (Chapter 2) for explanation of column headings.

South of Clay Pits Spring:

Appendix B.11a. Historical and current springsnail surveys at South of Clay pits Spring.

Spring:		South of Clay Pits Spring	
Species recorded:		*Pyrgulopsis isolatus*	*Tryonia variegata*
		Pyrgulopsis licina (NP)	
Historical surveys	**year**	***Pyrgulopsis***	***Tryonia***
Hershler and Sada	1985	x	x
Sada (unpubl.)	2008	x	x
Current springsnail occurrence/density		CPUE	CPUE
USGS (unpubl.)	2018	0	0
Service/Sada (unpubl.)	2020	ns	ns

Current Habitat Conditions/Notes

Recent site visits suggest extensive modification to develop spring.
USGS (2018) document significant vegetation change from historical surveys.
Further surveys required to determine the status of springsnails.
This site is only location for *Pyrgulopsis isolatus.*

CPUE: A= abundant, C= common, S=scarce
x = species present
NP = not petitioned
ns= not surveyed

Appendix B.11b. Threats for South of Clay Pits Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Vegetation and Soil Disturbance (Machinery)	2	4	6	5
Vegetation and Soil Disturbance (Recreation)	2	4	6	5

See methodology (Chapter 2) for explanation of column headings.

Marsh Spring:

Appendix B.12a. Historical and current springsnail surveys at Marsh Spring.

Spring province:		Marsh Spring			
Species recorded:		*Pyrgulopsis pisteri*		*Tryonia variegata*	
Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	x		x	
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	x	S	x	S
Service/Sada (unpubl.)	2020	x	C	x	C

Current Habitat Conditions/Notes

Site is in good condition with little disturbance.

Some red-rimmed melania present.

CPUE: A= abundant, C= common, S=scarce
x = species present
NP = not petitioned
ns= not surveyed

Appendix B.12b. Threats for Marsh Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Aquatic competition (invasive species)	2	1	1	0
Spring Modifications (Drought)	0	0	0	0

See methodology (Chapter 2) for explanation of column headings.

Mary Scott Spring:

Appendix B.13a. Historical and current springsnail surveys at Marsh Spring.

Spring:		Mary Scott Spring			
Species recorded:		*Pyrgulopsis nanus (NP)*		*Tryonia variegata*	
Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	x		x	
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	x	C	x	C
Service/Sada (unpubl.)	2020	x	C	x	C

Current Habitat Conditions/Notes

Site is in good condition downstream.

Some impact by herbivore trampling at the spring source.

Water is impounded in a small spring pool.

CPUE: A= abundant, C= common, S=scarce
x = species present
NP = not petitioned
ns= not surveyed

Appendix B.13b. Threats for South of Mary Scott Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Historical—Spring Modification (Impoundment)	2	2	0	0
Vegetation and Soil Disturbance (Ungulate Trampling)	2	2	0	0

See methodology (Chapter 2) for explanation of column headings.

North Indian Spring:

Appendix B.14a. Historical and current springsnail surveys at North Indian Spring.

Spring:	North Indian Spring		
Species recorded:		*Tryonia variegata*	
Historical surveys	**year**	***Tryonia***	
Hershler and Sada	1985	x	
Sada (unpubl.)	2008	x	
Current springsnail occurrence/density			CPUE
USGS (unpubl.)	2018	x	S
Service/Sada (unpubl.)	2020	x	S
Current Habitat Conditions/Notes			
Site is in good condition with little disturbance.			
Some impacts from aquatic competition (red-rimmed melania).			
Some areas show overgrown vegetation.			

CPUE: A= abundant, C= common, S=scarce

x = species present

NP = not petitioned

ns= not surveyed

Appendix B.14b. Threats for North Indian Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Aquatic competition (invasive species)	2	0	0	0
Spring Modification (overgrown vegetation)	2	0	0	0

See methodology (Chapter 2) for explanation of column headings.

South Indian Spring:

Appendix B.15a. Historical and current springsnail surveys at South Indian Spring.

Spring:	South Indian Spring		
Species recorded:		*Tryonia variegata*	
Historical surveys	**year**	***Tryonia***	
Hershler and Sada	1985	x	
Sada (unpubl.)	2008	x	
Current springsnail occurrence/density			CPUE
USGS (unpubl.)	2018	x	C
Service/Sada (unpubl.)	2020	x	C
Current Habitat Conditions/Notes			
Site is in good condition with little disturbance.			
Significant restoration by Ash Meadow Refuge.			
Aquatic competitor present (red-rimmed melania).			

CPUE: A= abundant, C= common, S=scarce

x = species present

NP = not petitioned

ns= not surveyed

Appendix B.15b. Threats for South Indian Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Aquatic competition (invasive species)	2	0	0	0
Spring Modification (overgrown vegetation)	2	0	0	0

See methodology (Chapter 2) for explanation of column headings.

North Scruggs Spring:

Appendix B.16a. Historical and current springsnail surveys at North Scruggs Spring.

Spring:		North Scruggs Spring			
Species recorded:		*Pyrgulopsis pisteri*		*Tryonia variegata*	
				Tryonia ericae	
Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	x			
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	x	C	x	C
Service/Sada (unpubl.)	2020	x	C	x	S

Current Habitat Conditions/Notes
Site is in good condition with little disturbance.
Significant restoration by Ash Meadow NWR.
Aquatic competitor present (red-rimmed melania).

CPUE: A= abundant, C= common, S=scarce

x = species present

NP = not petitioned

ns= not surveyed

Appendix B.16b. Threats for North Scruggs Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Aquatic competition (invasive species)	2	3	0	1
Spring Modification (overgrown vegetation)	2	3	0	5

See methodology (Chapter 2) for explanation of column headings.

South Scurggs Spring:

Appendix B.17a. Historical and current springsnail surveys at South Scruggs Spring.

Spring:		South Scruggs Spring			
Species recorded:				*Tryonia variegata*	
Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985			x	
Sada (unpubl.)	2008				
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018			x	A
Service/Sada (unpubl.)	2020			x	A

Current Habitat Conditions/Notes

Site is in good condition with little disturbance.

Significant restoration by Ash Meadow NWR.

Aquatic competitor present (red-rimmed melania).

CPUE: A= abundant, C= common, S=scarce

x = species present

NP = not petitioned

ns= not surveyed

Appendix B.17b. Threats for South Scruggs Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Aquatic competition (invasive species)	2	0	0	0

See methodology (Chapter 2) for explanation of column headings.

School Spring:

Appendix B.18a. Historical and current springsnail surveys at School Spring.

Spring:		School Spring			
Species recorded:		*Pyrgulopsis pisteri (NP)*		*Tryonia variegata*	
		Pyrgulopsis sanchezi (NP)			

Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008				
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	x	A	x	C
Service/Sada (unpubl.)	2020	x	A	x	A

Current Habitat Conditions/Notes

Site is in good condition with little disturbance.

Significant restoration by Ash Meadow NWR.

No significant threats exclusive of drought conditions.

CPUE: A= abundant, C= common, S=scarce
x = species present
NP = not petitioned
ns= not surveyed

Appendix B.18b. Threats for School Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Spring Modifications (Drought)	4	unknown	unknown	unknown

See methodology (Chapter 2) for explanation of column headings.

Near Crystal Reservoir Springs:

Appendix B.19a. Historical and current surveys at Near Crystal Reservoir Spring.

Spring:	Near Crystal Reservoir				
Species recorded:		*Pyrgulopsis licina (NP)*		*Tryonia variegata*	
Historical surveys	**year**	***Pyrgulopsis***		***Tryonia***	
Hershler and Sada	1985	x		x	
Sada (unpubl.)	2008	x		x	
Current springsnail occurrence/density			CPUE		CPUE
USGS (unpubl.)	2018	-	-	-	-
Service/Sada (unpubl.)	2020	ns		ns	

Current Habitat Conditions/Notes
Surveyors were unable to thoroughly sample habitat thoroughly
Significant vegetation growth
No springsnails recorded

CPUE: A= abundant, C= common, S=scarce
x = species present
NP = not petitioned
ns= not surveyed

Appendix B.19b. Threats for Near Crystal Reservoir Spring.

Threat (Source)	**Immediacy**	**Intensity**	**Exposure**	**Response**
Spring Modifications (overgrown vegetation)	4	unknown	unknown	unknown

See methodology (Chapter 2) for explanation of column headings.