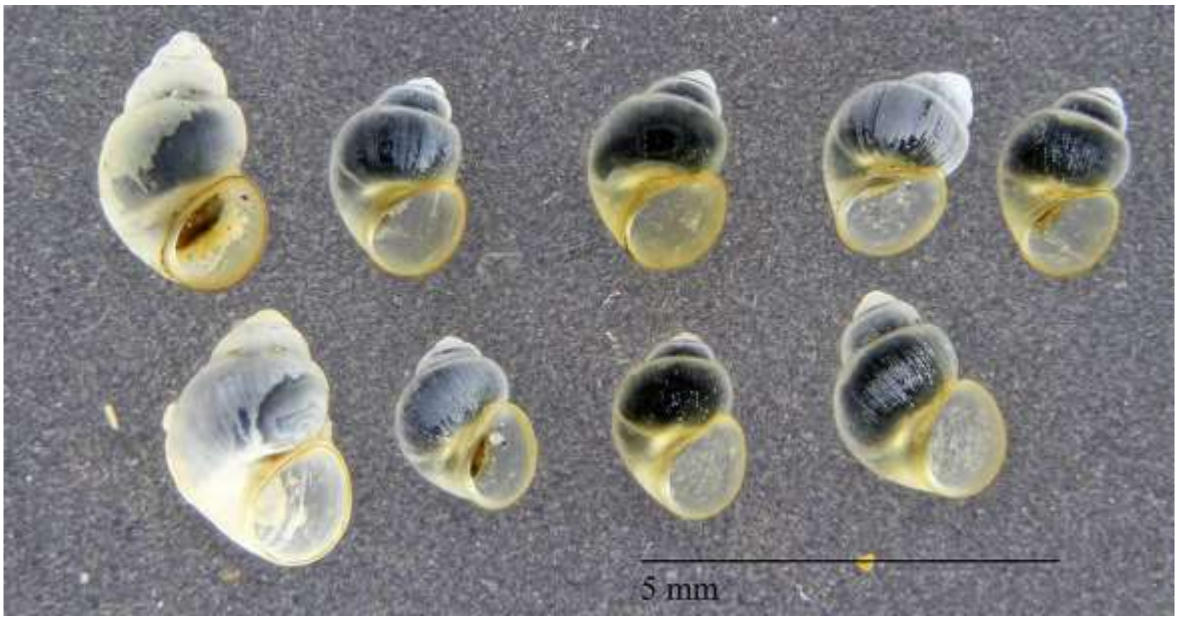
CONSERVATION STRATEGY FOR SPRINGSNAILS IN NEVADA AND UTAH



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ABBREVIATIONS, ACRONYMS, AND GLOSSARY

Abbreviations and Acronyms

Agreement	The Conservation Agreement for Springsnails in Nevada and Utah
BLM	Bureau of Land Management
DRI	Desert Research Institute
ESA	Endangered Species Act of 1973, as amended
NDNH	Nevada Division of Natural Heritage
NDOW	Nevada Department of Wildlife
NEPA	National Environmental Policy Act
NPS	National Park Service
NRCS	Natural Resources Conservation Service
SCT	The Nevada-Utah Springsnail Conservation Team
SNWA	Southern Nevada Water Authority
SSA	Species Status Assessment
SSI	Museum of Northern Arizona Springs Stewardship Institute
Strategy	The Conservation Strategy for Springsnails in Nevada and Utah
TNC	The Nature Conservancy
UDWR	Utah Division of Wildlife Resources
UGS	Utah Geological Survey
UNLV	University of Nevada at Las Vegas
UNR	University of Nevada at Reno
USFS	US Forest Service
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey

Glossary

Abundant: A springsnail population is enormous, readily observed, and obviously healthy. Using the Sada (2019) springsnail monitoring methods (Appendix B), a mean catch per unit effort of >20 individuals/sample.

Adaptive management: Adaptive management is designed to bring new information immediately into management decisions. The effectiveness of all conservation measures and monitoring methods will be periodically reviewed and evaluated by the implementing cooperators through the Springsnail Conservation Team (SCT). Based on such evaluation, appropriate modifications to methods, actions, and strategies will be made to ensure scientific rigor and the efficacy of conservation measures.

Aquifer: Rock or sediment layer that contains and transmits groundwater

Candidate species: Those species for which the U.S. Fish and Wildlife Service (USFWS) has sufficient information on file on the biological vulnerability and threats to support issuance of a proposed rule to list under the Endangered Species Act (ESA; 1973, as amended), but issuance of the proposed rule is precluded by higher listing priorities (https://nctc.fws.gov/Pubs9/esa_cand01.pdf).

Clade: A monophyletic group of organisms, including all descendants from a common ancestor.

Climate change: Change in the mean or variability of one or more measures of climate (e.g., temperature or precipitation) persisting for an extended period (decades or longer).

Co-lead responsibility: Participant and signatory to the Agreement and the Strategy, with shared responsibility where one or more other participants to ensure an identified conservation action or activity will be implemented.

Common: Using the Sada (2019) springsnail monitoring methods (Appendix B), a mean catch per unit effort of 6-20 individuals/sample.

Connectivity: Pathways across and through aquatic or terrestrial blocks of habitat which facilitate and maintain the interchange of individual animals among sub-populations.

Conservation action: An action taken to conserve or preserve natural resources.

Conservation unit: A group of population units that either exhibit connectivity or are not separated by known barriers. Connectivity can be by perennial or intermittent flowing water or by landscape features that permit dispersal.

Crenobiontic Species: Spring dependent species, including springsnails

Detritus: Dead particulate organic material of plants and animals.

Disease: Pathogenic infection of an organism from an external source which may have a chronic or acute negative effect on that organism at an individual or population level.

Distinct population segment: An animal population unit that can be defined as geographically and/or genetically discrete and significant to the species as a whole for the purpose of listing consideration under the ESA. While applied to vertebrate populations in the ESA, the concept may be applicable to springsnail species conservation planning.

Endangered Species Act Endangered Species Act (ESA 1973, as amended).

Endorheic: Internally draining; a land-locked drainage network, such as the Humboldt River.

Fragmentation: The disruption of extensive habitats into isolated and/or small patches.

Genotype: A population that is genetically distinguishable from other populations.

Haplotype: A suite of alleles (DNA variants or polymorphisms) or a set of single nucleotide polymorphisms (SNPs) found on the same chromosome that tend to be inherited together; a clade.

Helocrene spring: A wet meadow springs ecosystem, with flow emerging from low gradient wetlands; often with indistinct or multiple seeping sources.

Historic range: A geographical area in which a species has been found or is known to have once inhabited.

Inventory: The process of conducting surveys to determine the total distribution and abundance.

Lead responsibility: Participant and signatory to the Conservation Agreement and the Strategy with primary responsibility to ensure an identified conservation action or activity will be implemented.

Lentic: Standing water habitats, including natural and beaver ponds, wetlands, and impoundments.

Limiting factor: Resources or environmental conditions that limit the growth, abundance, or distribution of an organism or a population of organisms in an ecosystem.

Limnocrene: A type of springs ecosystem with discrete groundwater source(s) that emerges and forms one or more pools.

Local aquifer: Groundwater system fed by precipitation that has infiltrated from a nearby, generally small catchment.

Lotic: Flowing water habitats, such as streams and rivers.

Macroinvertebrate: An organism without a vertebral column that is visible to the eye without the aid of a microscope.

Madicolous: A lotic aquatic habitat characterized as a steeply angled sheet of white water.

Metapopulation: A conservation unit in which characteristics, such as a source/sink relationship, have been demonstrated to occur, or *population units* that are interconnected within the same drainage systems and are interdependent.

Minimum viable population: The minimum population size required to ensure the sustainability of a population.

Monitoring: Scientific study of the properties, characteristics, or condition of variables of interest through time.

Native: A species that historically occurred in a specific area or habitat.

Non-native: A species that historically did not occur within a region and that now inhabits that landscape as a result of human actions.

Occupied habitat: "Specific areas within the geographical area occupied by the species, which contain the 'physical or biological features essential to the conservation of the species' and may require special management protections" (https://fas.org/sgp/crs/misc/LSB10234.pdf: p. 2). Principally applied to more mobile species, such a definition does not well apply to native springsnail populations, which have little extra-spring dispersal capability. Therefore, springsnail presence defines habitat occupancy.

Participant/cooperator: Any entity that assists in the development and implementation of conservation actions, whether or not a signatory to the Conservation Agreement and the Strategy.

Population: A particular species in a particular group or in a definable place

Population unit: A local population of randomly breeding individuals (a deme). A population unit typically occupies a single breeding site, such as a single or a small group of springs.

Potential habitat: Areas that contain one or more key elements of springsnail habitat, or areas of unoccupied habitat (both surveyed or unsurveyed) where springsnails could be translocated.

Predation: The capture and consumption of one animal by another; applies to all life stages of the organism.

Protocol: A procedure for monitoring or other activity which conforms to standard biological practices and has been identified by the SCT as an accepted standardized methodology for conducting that activity.

Rare: Using the Sada (2019) monitoring methods (Appendix B), a mean catch per unit effort of <1.0 springsnails/sample.

Redundancy: The ability of a species to withstand catastrophic events, which is related to the number, distribution, and habitat connectivity of populations.

Regional aquifer: A large groundwater system generally characterized by water that is warmer and moves slowly 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. For example, the metric is used to describe changes in the density of individuals/sample across the gradient from springbrook source to the terminus of the channel.

Relict: A persistent remnant of an otherwise extinct (locally or globally) organism.

Representation: The distribution of a species across environmental gradients over time, and characterized by the breadth of genetic and environmental diversity within and among populations.

Resiliency: The ability of the species to recover from stochastic disturbance events, as indicated by monitoring population size, growth rate, and habitat quality.

Restoration: Specific actions taken to improve or return habitat or associated ecosystems to potential natural conditions.

Rheocrene: A type of springs ecosystem in which discharge emerges into one or more defined stream channels.

Risk: For the purposes of this document, risk is quantifiable as an ordinal, integer, or ratiometric value of a threat or a stressor's impact on a population or its habitat.

Risk assessment: The process of using the best available scientific information to quantitatively evaluate the array and severity of threats and stressors affecting a species or its habitat. Risk assessment can be used in a comparative fashion to prioritize among species or habitats, or used over time to establish trends in population integrity.

Risk factor: Threats (potential impacts) and stressors (actual impacts).

Scarce: Using the Sada (2019) monitoring methods (Appendix B), a mean catch per unit effort of 1-6 springsnails/sample.

Sentinel site: A specific location for defined, periodic monitoring of animals or habitat that provides benchmark data for assessing changes in status or condition.

Sink population: A population which has a local mortality that exceeds local reproductive success thus is unsustainable without immigrants from outside sources.

Source: A habitat in which local reproductive success within a population exceeds local mortality.

Source population: An actively breeding population that has an average birth rate that exceeds its average death rate, and thus produces an excess of animals that may disperse to other areas.

Species: A population of actually or potentially interbreeding individuals that produce reproductively viable offspring, and which is both morphologically and genetically distinguishable.

Species management plan: Guidance document prepared by one or more collaborators that identifies detailed actions and activities for conservation of a springsnail taxon throughout its range.

Species monitoring plan: Guidance document prepared by one or more collaborators that defines the structure, timing, protocols, and locations for short- and long-term population monitoring, subject to adaptive management review by the SCT.

Springbrook: A stream fed by a spring. A springbrook also may be called a spring-run or a springs runout channel.

Springsnail: A species-rich suite of small-sized freshwater gastropods in the families Amnicolidae, Assimineidae, Cochliopidae, Hydrobiidae, Lithoglyphidae, and Tateidae in the superorder Caenogastropoda, subclade Hypsogastropoda, order Littorinimorpha (Neotaenioglossa), and superfamily Truncatelloidea, as well as Semisulcospiridae in the superfamily Cerithioidea, and other taxa elsewhere. Springsnails are found throughout the non-Polar world, and are particularly diverse in the Basin and Range geologic province.

Stressor (ecological): Any physical, chemical, or biological alteration of the environment that reduces the viability of an individual, a population, or a species, or the viability of its habitat.

Subpopulation: A geographically distinct population segment (see population unit).

Survey: Field assessment to determine a species or habitat distribution, abundance, and/or type.

Threat: A potential physical, chemical, or biological anthropogenic alteration of the environment that is reasonably likely to negatively affect an organism, population, species, or its habitat.

Viable population: A population that maintains its reproductive vigor and its potential for evolutionary adaptation.

EXECUTIVE SUMMARY

This Nevada and Utah Springsnail Conservation Strategy (“Strategy”) is a comprehensive and proactive 10-year plan to protect 103 species of springsnails and their habitats (primarily springs) in relation to the objectives established in the Conservation Agreement (“Agreement”). The Agreement was signed in 2018 by state and federal land and natural resource agencies and The Nature Conservancy (TNC) in the two states. Springsnails constitute a large number of tiny, unique and often site-specific aquatic gastropods in the superfamilies Truncatelloidea and Cerithioidea. Springsnails and their habitats are threatened by both local and regional stressors, and several species are thought to have recently gone extinct. To prevent further loss of this unique component of Nevada and Utah’s natural heritage, the Agreement authorizes the two states to assemble a Springsnail Conservation Team (SCT). The SCT is led by the Nevada Department of Wildlife (NDOW) and the Utah Division of Wildlife Resources (UDWR), and includes representatives of the signatory agencies, as well as The Nature Conservancy (TNC). The Museum of Northern Arizona Springs Stewardship Institute (SSI) in Flagstaff was contracted to assist the SCT in the development of this document in 2019-2020. Successful achievement of Agreement objectives will protect the diverse springsnail assemblage and their habitats in Nevada and Utah, thereby precluding the need for federal listing of those species.

The objectives in the Agreement include: 1) compiling springsnail ecology and distribution data into a single database; 2) identifying, assessing, and reducing threats to 103 springsnail taxa and their habitats; 3) maintaining, enhancing, and restoring habitats; 4) developing and maintaining the SCT; and 5) creating an effective education and outreach program for landowners, agencies, and the general public. The SCT held several in-person and multiple webinar meetings in 2019 and 2020 to initiate the Strategy, query the members, and conduct data-mining. SSI assembled information and literature on each taxon in the two states and entered the data into the Springs Online database (SpringsData.org). The database is a password-protected, user-friendly, online information management system used to archive and report on species taxonomy, distribution, and population and conservation status data, and includes diverse information on springs and springs-dependent biota. This information was used to electronically generate individual species reports, which can be easily updated as new information emerges on each species.

Within each of the Agreement objectives, the Strategy discusses issues ensuring springsnail species representation, resiliency, and redundancy, which are regarded as the USFWS hallmarks of population integrity. The Strategy describes the threats and challenges to effective springsnail conservation, and the process through which the SCT will address springsnail conservation. Appendix A of the Strategy provides descriptive information on each springsnail species in the Great Basin, and the Colorado, Amargosa, and upper Snake River basins in Nevada and Utah. Appendix B-E provide tools for monitoring, agency lexicon definition, stakeholder responsibilities, and comparative risk assessment and action prioritization in relation to local and far-field threats and stressors, respectively. Also included are a comprehensive, searchable bibliography on Nevada and Utah springsnails (Appendix F) and documentation of springsnail stewardship accomplishments (Appendix G). The issues and tools presented in this Strategy and through the database enable the SCT to monitor, prioritize, and readily report on springsnail conservation progress over the decadal life of the Agreement.

1. Introduction, Purpose, Goals, Objectives, and Criteria

Introduction

Springsnails are generally tiny aquatic, fresh- or brackish-water gastropods in the order Neotaenioglossa and the superfamilies Truncatelloidea and Cerithioidea. Springsnails are found throughout the non-ice-dominated world (e.g., Miller et al. 2018). They are highly diverse, and often closely adapted to individual springs, and their conservation has become the subject of increasing conservation concern (Ledyeard et al. 2004, Hershler et al. 2014a, Johannes and Clark 2016). More than 180 species of springsnails have been described in North America, and they are particularly diverse in arid Nevada and Utah, where at least 103 taxa have been identified (Fig. 1; Appendices A, E). These “target” species typically occur in or very near springs sources, and tend to be local endemics, in many cases occurring at only one or a few water sources and tightly adapted to the water quality and habitat conditions of their individual springs. Increasing concern for the viability of springsnail populations and the habitats they occupy in Nevada, Utah and elsewhere has arisen due to intensive groundwater extraction and use, the widespread use of springs for domestic and agricultural purposes (Noss 2000, Hershler et al. 2014a, Hershler and Liu 2017), and the limited availability of reliable information on the status of many populations. Two southwestern species recently were federally listed (i.e., Black River springsnail - *Pyrgulopsis trivialis*, and San Bernardino springsnail - *P. bernardina*) in Arizona, and several southwestern species have reportedly gone extinct in the past few decades. The contemporary status of many populations and species remains unknown; however, Sada and Lutz (2016) reported that 83 percent of 2,256 springs inventoried in the Great Basin and Mojave deserts between the 1980s and 2013 were disturbed by human activities, results corroborated by Stevens et al. (2020) in the Nevada and Utah portions of the Colorado River basin. Declining health of springsnail populations and their habitats can lead the U.S. Fish and Wildlife Service (USFWS), as well as state wildlife agencies to invoke protection of springsnails under the Endangered Species Act (ESA; 1973, as amended), or under state statutes.

This Conservation Strategy for Springsnails in Nevada and Utah (Strategy) presents an organizational framework and appendices of information for management objectives and prioritized conservation actions to reduce, remedy, or eliminate threats to springsnail populations and habitats in the two states. If effective, the Strategy will prevent population declines and stabilize or increase at-risk springsnail populations. The springsnail conservation plan and tools presented in the Strategy are designed to improve or protect the hydrologic and habitat functionality of springs at which springsnails occur. By protecting or improving springsnail population health and persistence, the Strategy will reduce or eliminate the need for federal or state listing of springsnails and other springs-associated biota. Monitoring protocols (Appendix B) and other tools are provided to assist managers prioritize information gathering and management planning, implementation, and monitoring (Appendices C-G). Over the long-term, implementation of the Strategy is expected to improve springs ecosystem integrity and springsnail population persistence.

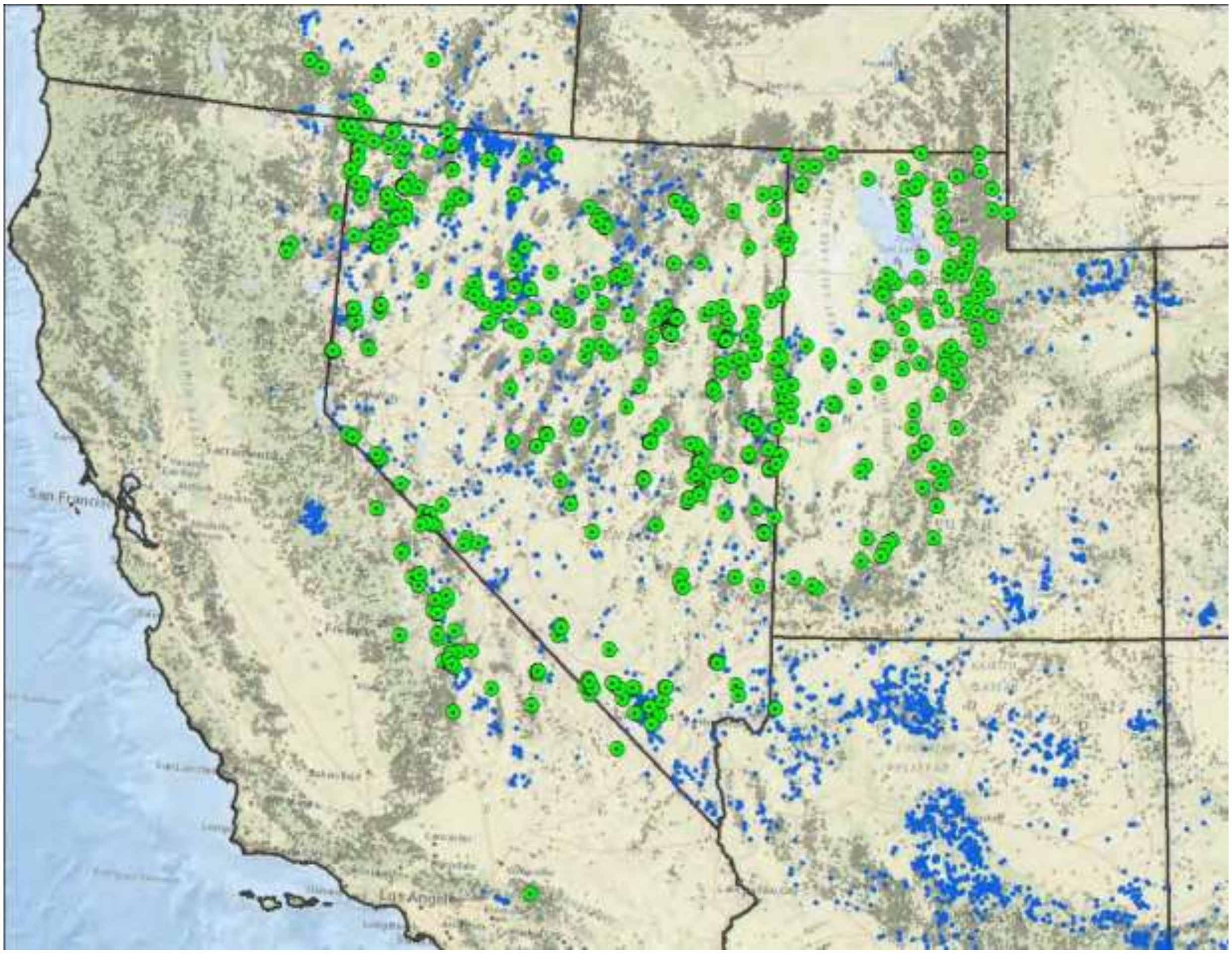

Figure 1: Map of the estimated 37,121 springs reported in Nevada and Utah (gray dots), with inventoried springs as blue dots, and springs reported to support springsnails indicated as green dots. Mapping data were derived from the Springs Stewardship Institute Springs Online database (SpringsData.org; map courtesy of J. Jenness, SSI). Some Nevada or Utah species occur in the Great Basin outside of the two states.

The Agreement was developed, in part, in response to petitions submitted by Forest Guardians (2007) and the Center for Biological Diversity et al. (2009) to the USFWS to list 47 Great Basin and Mojave Desert springsnail species under the ESA (USFWS 2011). The USFWS's 90 Day Finding reviewed 39 of the original 42 species (three species had been reviewed in 2009), reporting that seven species did not warrant listing. The remaining species are being reviewed in several separate 12 Month Findings. At present, these include 14 Nevada species (USFWS 2017); three Utah-Nevada species (USFWS planned release 2020); 11 southern Nevada species (USFWS planned release 2021). Seven northern NV species (USFWS planned release 2022) springsnail species recently have been, or currently are, under review for possible listing under the ESA.

Currently, 103 target springsnail species are recognized in Nevada and Utah. These species are included in Nevada or Utah State Wildlife Action Plans as species of concern, and are listed here (Nevada Wildlife Action Plan Team 2012, Utah Division of Wildlife Resources 2015). The data on population distribution, status, and the last reported surveys of each species is critical information to prevent population extirpations or extinctions of this large number of springs-dependent species, and this information is provided in Appendices A and E.

The importance of collaborative identification, planning, and implementation of conservation measures for springsnail species is recognized in the Agreement. This collaborative effort involves staff of state and federal resource agencies, non-governmental organizations, as well as springsnail and springs experts. Native American Tribes, private landowners, and the public also are invited to participate. Signatories to the Agreement concur that implementing the conservation objectives, strategies and actions defined herein will benefit springsnails and their habitats in Nevada and Utah. The Strategy is intended to secure species, provide habitat conservation, and significantly reduce or eliminate threats, thereby supporting the persistence of these species and their habitats. Such conservation benefits may contribute to improved ecological integrity of other springs and springs-dependent species. This Strategy presents prioritized goals, objectives, and actions that are necessary to reduce or eliminate threats and provide for self-sustaining springsnail populations in Nevada and Utah.

Over time, and as conservation efforts increase, additional springsnail species and population information will be gathered, including that on species ranges, habitat requirements and ecology. This also will include the documentation of the loss of some populations and perhaps extirpation/extinction of species of conservation concern, as well as taxonomic revision. Such information has four implications on Strategy development and implementation. 1) The state of knowledge regarding springsnails continues to evolve as additional information is compiled, and therefore the Strategy needs to emphasize flexibility and commitment to continuing inventory, monitoring, and assessment. 2) The Strategy should provide for annual review and evaluation of the success of management or restoration actions, including options for emergency salvage and captive propagation, and with metrics and milestones that support annual and multi-year review of priorities and program success. 3) The Strategy needs a well-organized information management system to foster cooperation among the collaborating agencies, and to accommodate new information as it arises, including climate change adaptation and other information that may substantially alter previous priorities. Lastly, and given the often-polarized nature of water resources use in the region, 4) the Strategy should strongly promote outreach, education, and public discussion about the need for and value of sustainable management of water and natural resources.

Effective conservation of Nevada and Utah springsnails requires reducing or eliminating population and habitat threats, improving degraded habitat conditions, and rehabilitation of the natural functions of springs and wetlands ecosystems that support these and associated species. This Strategy describes why and how the states of Nevada and Utah developed a comprehensive, multi-species springsnail conservation approach, including program purpose, goals, objectives, strategies, and actions. The Strategy also describes springsnail taxonomy, current status, ecology, information gaps, research needs, information management, stewardship planning, monitoring/feedback, an implementation plan and schedule, and an outreach and education plan. Information is included on gastropod taxa not yet considered in the Agreement. In addition, a comprehensive springsnail bibliography is electronically appended, along with appendices on the conservation plan, detailed species accounts, and monitoring and sampling protocols.

The information compiled in this effort has been organized and archived into Springs Online (springsdata.org), a secure, online information management system to readily compile and present species taxonomic, distribution, and population status data, and facilitate reporting. Springs Online data are used to generate a daily-updated geodatabase for SCT collaborators, when they are interested in updating their information.

Purpose

The purpose of this Strategy is to outline a framework for management actions to achieve the goal of long-term conservation of springsnails and their habitats in Nevada and Utah. This Strategy identifies actions that are necessary to reduce or eliminate threats and provide for the long-term conservation of springsnails in these states, such that protection under the ESA may not be necessary. Conservation of Nevada and Utah springsnails will require reducing or eliminating threats, improving degraded habitat conditions, and restoring many of the natural functions of associated springs and stream ecosystems. These habitat protection and restoration efforts will also benefit many other threatened and sensitive species that co-occur in these ecosystems, will reduce habitat degradation and downstream habitat losses, and may enhance agricultural and recreation opportunities and land values (Nevada Wildlife Action Plan Team 2012, Utah Division of Wildlife Resources 2015).

Goals

The goal of the Strategy is long-term conservation of the target springsnail species and their habitats in Nevada and Utah. These goals will be achieved by accomplishing the objectives, strategies, and actions described below. The time frame for this effort is decadal (2017-2027), with annual and five-year reviews of program progress. Renewal of the program after 2027 is subject to discussion among the signatories.

Objectives, Strategies, Actions, and Criteria

The following objectives were accepted by the signatory parties to the Agreement (2017) as components of the Strategy:

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

These objectives are listed in relation to associated strategies and actions in Table 1, with signatory agency responsibilities in Appendix D. Each objective and its associated strategies and actions have standards of success, as documented in Appendix D, and each benefits the overall Strategy to meet the requirements of the Agreement.

Table 1: Objectives, strategies, and actions for the Nevada and Utah Springsnail Conservation Strategy.

Objective 1: Compile known springsnail distribution, status, and habitat data in to 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.
Strategy 1. Create a comprehensive species list of the springsnail species of Nevada and Utah.
Action 1. Compile available scientific information and publications regarding distribution, abundance, population stability, and habitat requirements for the target springsnail species.
Action 2. Regularly incorporate new information into the database, and occasionally convene a state of knowledge symposium to integrate historic and new information.
Action 3. Evaluate the adequacy of data contained in the database and identify additional data needed to inform springsnail management/conservation.
Action 4. Create a working relationship with private and public landowners to ensure comprehensive and current knowledge on springsnail distribution, status, and habitat data.
Action 5. Develop strategy, rationale, and contingencies for addressing taxonomic revisions, reclassification, discovery of new species and haplotypes, extirpation/extinction of SCT-identified species, and potential rediscovery of species thought to be extinct.
Strategy 2. Fill and/or limit data gaps and manage the database.
Action1. Conduct literature research and field surveys for missing species information.
Action 2. Develop standardized sampling methods and protocols for springsnail and associated habitat data collection, information management, data entry, recording, and distribution of information for all partners, signatories, and outside agencies (e.g., Utah Geologic Survey; UGS), experts, and citizen scientists to use.
Action 3. Develop a routine program/protocol for springsnail population and habitat inventory and monitoring data collection, compilation, and entry into Springs Online.
Action 4. Develop a framework for identifying and prioritizing research needs.
Action 5. Develop a data-sharing agreement among signatory parties and other partners to ensure maximum utility of the database for springsnail conservation, and which protects sensitive and proprietary information.

Action 6. Develop and implement a plan for long-term maintenance of the database and data quality assurance.
Action 7. Seek additional funding and agency assistance to fund recognized research needs.
Objective 2: Identify, assess, and reduce known and potential threats to springsnail populations and their associated habitats at occupied sites.
Strategy 1. Develop and implement standardized habitat and risk assessment protocols for all occupied sites.
Action 1. Develop a process for the SCT to annually prioritize the springsnail species and habitats for detailed risk assessment.
Action 2. Evaluate each springsnail species susceptibility due to limitations of population size, restricted distribution restriction, and adaptability (representation, redundancy, or resiliency) and unknowns thereof, as part of an overall evaluation of the condition and vulnerability of the species and the need for prioritization monitoring and risk reduction.
Action 3. For each occupied habitat, assess its current condition as part of an overall evaluation of the condition and vulnerability of habitat (and occupying species) and the prioritization of monitoring and risk reduction efforts.
Action 4. Create a working relationship with private and public landowners to ensure recognition and understanding of springsnail habitat preservation needs, and to work to remove or reduce known stressors.
Action 5. For each occupied habitat, identify and assess on-going stressors and potential future local threats of degradation (activities/developments with a likelihood of occurring), and the significance of the impacts, as part of an overall evaluation of the condition and vulnerability of habitat (and occupying species) and the prioritization of monitoring and risk reduction efforts.
Action 6. For each occupied habitat, identify and assess any existing far-field (non-local/off-property) causes of degradation, and the significance of the impacts, as part of an overall evaluation of the condition and vulnerability of habitat and occupying species, and the prioritization of monitoring and risk reduction efforts.
Action 7. For each occupied habitat, identify and assess any potential future far-field causes of degradation (activities/developments with a likelihood of occurring, such as climate change impacts on habitat), and the significance of the impacts, as part of an overall evaluation of the condition and vulnerability of habitat (and occupying species) and the prioritization of monitoring and risk reduction efforts.
Strategy 2. To the extent feasible, remove or reduce current risks, and monitor and evaluate occupied sites to ensure the continued survivability of those populations.
Action 1. Develop a process for the SCT to annually prioritize the locations for monitoring, risk reduction, and future conservation efforts to springsnail species and habitats.

Action 2. For each occupied habitat, identify remediation measures that may reduce the impacts of **existing local** stressors, and the feasibility and likelihood of success if undertaken, as part of an overall evaluation of the condition and vulnerability of habitat (and occupying species) and the prioritization of monitoring and risk reduction efforts.
Action 3. For each occupied habitat, identify remediation measures that may reduce (or preclude) the impacts of **potential future local causes** (threats) of degradation, and their feasibility and likelihood of success if undertaken, as part of an overall evaluation of the condition and vulnerability of habitat (and occupying species) and the prioritization of monitoring and risk reduction efforts.
Action 4. For each occupied habitat, identify remediation measures that may reduce the impacts of **existing far-field stressors**, and their feasibility and likelihood of success if undertaken, as part of an overall evaluation of the condition and vulnerability of habitat (and occupying species) and the prioritization of monitoring and risk reduction efforts.
Action 5. For each occupied habitat, identify remediation measures that may reduce (or preclude) the impacts of potential **future far-field causes of degradation**, and their feasibility and likelihood of success if undertaken, as part of an overall evaluation of the condition and vulnerability of habitat and the prioritization of monitoring and risk reduction efforts.
Action 6. Integrate the results of assessments of current habitat condition, the significance of impacts of existing and potential (future) local and far-field causes of degradation, and the feasibility/likelihood of successful remediation for each occupied habitat, to evaluate the condition and vulnerability of the occupied habitat and prioritize monitoring and risk reduction efforts.
Action 7. Integrate the results of assessments of the condition and vulnerability of each species occupied habitats to evaluate overall habitat condition/vulnerability as part of an evaluation of the condition and vulnerability of the species and the prioritization of monitoring and risk reduction efforts.
Action 8. For each springsnail species, integrate assessments of the condition/vulnerability of its occupied habitats, and susceptibility due to limitations in its representation, redundancy, or resiliency (or unknowns thereof), to evaluate the overall condition and vulnerability of the species to extinction, and prioritize monitoring and risk reduction efforts.
Action 9. Implement data collection and risk reduction efforts, prioritized using the results of assessments of the overall condition and vulnerability of species and occupied habitats.
Action 10: Evaluate emergency salvage options for each species, and its potential for captive rearing.
Strategy 3. Ensure risk assessment and remediation methods are periodically updated and effectively implemented.

Action 1. Update vulnerability assessments periodically using new and updated information to evaluate the success of the conservation program and reprioritize data collection and risk reduction efforts.
Action 2. Update vulnerability assessment methodologies as needed and determined by the SCT.
Objective 3: Maintain, enhance, and restore springsnail habitats in Nevada and Utah to ensure the continued persistence of all species.
Strategy 1: Identify the range of habitat conditions that are optimal for each springsnail species.
Action 1: Identify healthy populations and determine which habitat qualities allow the population to be self-sustainable and identify limiting factors.
Action 2: Ensure optimal habitat conditions and requirements are met at each occupied site to the extent feasible through enhancement or restoration projects.
Strategy 2: Create an inventory and monitoring program that involves adequate monitoring of habitat quality and needs, and identifies new or previously unrecognized risks.
Action 1: Organize and conduct periodic springsnail inventory, monitoring, and information management trainings or refresher courses for SCT staff, experts, and the interested public.
Action 2: Conduct monitoring activities.
Action 3. Ensure the accuracy, adequacy, and availability of information through the information management system.
Action 4: Evaluate and statistically test the quality of monitoring data (methods to be determined by the SCT and its advisors).
Strategy 3: Develop and implement a program to encourage and incentivize voluntary conservation of springsnail species and habitats on non-federal, Tribal, and private lands.
A*ction 1:* Determine extent of springsnail and associated habitat occurrence on private lands within Nevada and Utah.
Action 2: Develop Best Management Practices (BMPs) and guidance to assist private landowners in implementing voluntary conservation actions to conserve spring and spring outflow habitats.
Action 3: Identify signatory and non-signatory partners with programs for landowner assistance that could assist in implementing actions.
Action 4: Implement the strategy and approach to encourage and incentivize voluntary conservation, where the latter are needed.
Strategy 4: Evaluate and ensure on-going protection of springsnail populations and habitats.
Action 1: Annually review of the adequacy of protection of each springsnail population.
Action 2: Use Objective 3, Strategy 4, Action 1 to enhance population and habitat monitoring and protection using direct habitat rehabilitation as well as outreach efforts.

Objective 4: Develop a Springsnail Conservation Team (SCT), which will be tasked with development and implementation of the Strategy and coordinating on-the-ground conservation actions for identified springsnail species and habitats.
Strategy 1: Ensure SCT involvement, interaction, and communications.
Action 1. Convene regular, effective, well-organized, well-documented meetings.
Action 2. Develop long-term support for the SCT.
Sction 3. Develop long-term support for SCT information management.
Action 4: Review SCT progress, effectiveness, and approach annually.
Objective 5. Develop 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.
Strategy 1: The SCT will develop "messages" and a public relations strategy about the need for springs and springsnail conservation.
Action 1: The SCT will collaboratively develop outreach messages using outreach personnel available from partners and experts.
Action 2: Develop benchmarks and metrics to evaluate the effectiveness of the program.
Action 3: The SCT will test those messages for effectiveness and marketability.
Strategy 2: Develop partnerships with private landowners and incentivize voluntary springsnail and spring habitat conservation.
Action 1: Identify and reach out to landowners about springsnail species and habitat that might occur on their land.
Action 2: Develop and implement incentives to stimulate voluntary conservation of springsnails and their habitats.
Strategy 3: Monitor the effectiveness of the outreach program.
Action 1: Participate in locally led efforts in order to develop relationships with private landowners (e.g., Conservation District meetings, NRCS Local Area Work Groups, etc.).
Action 2: Maintain consistent relationships with agencies and landowners to monitor the effectiveness of the outreach program.
Action 3: Report annually on the effectiveness of the outreach program and use challenges and lessons learned to improve the effectiveness and advertisement of the program.

2. Springsnail Evolution and Taxonomy

Springsnail Evolutionary History

Springsnails are renowned as a hyper-diverse, springs-dependent (crenobiontic) group of snails that are highly prone to endemism and often closely adapted to individual springs (e.g., Hershler and Liu 2017, Miller et al. 2018). Their present global distribution and diversity has been the result of a lengthy and complex evolutionary history (Table 2). Truncatelloidean (Rissooidean) fossils are known from the middle and later Paleozoic eon (400 to 250 million year ago) and the early Triassic periods (reviewed by Frýda et al. 2008, Ponder et al. 2008).

Table 2: Summary of global springsnail diversity by continent.

Continent	Number of Springsnail Species	Percent of Endemic Mollusca	Reference
Africa	69	11	Van Damme et al. 2010, Seddon et al. 2011
Australia	252	49	Strong et al. 2008
Europe	610	69	Cuttelod et al. 2011
North America	180	18	Hershler and Liu 2017
South America	---	---	No data found

However, the fossil record is difficult to interpret given that only the shells typically are preserved. Much recent springsnail phylogeny and classification has been refined and improved with soft tissue anatomy and genetic studies. In more recent geologic time, particularly the Pleistocene (2.5 million to 11,700 years ago), and Holocene (11,700 BCE to the present), repeated cycles of population isolation and mixing through major, long-term environmental changes have resulted in the evolution of many springsnail species. The genera *Pyrgulopsis* (Hydrobiidae) and *Tryonia* (Cochliopidae) are particularly species rich in Nevada and Utah.

Extensive morphological and genetic analyses allowed Hershler and Liu (2008) to map the evolutionary history of the genus *Pyrgulopsis* in the Death Valley and the Amargosa River basin in Nevada and California. Their analyses revealed a complex evolutionary radiation since the late Miocene epoch over the last six million years through repeated geomorphological and climate changes. Those environmental changes included the filling and drying out of large, endorheic Pleistocene lakes, most recently Lakes Manley, Bonneville, Lahontan, and others as climate has fluctuated over the past two million years. Those climate and habitat changes created population isolating conditions that influenced the speciation of springsnails and other aquatic biota, such as cyprinodontid pupfish. Also, Hershler and Liu (2008) reported that several springsnail lineages that were erratically distributed, likely due to avian dispersal across the western Great Basin. Nonetheless, the isolation of most springsnail populations under changing climates, adaptation to diverse but internally ecologically constant conditions of individual springs, as well as erratic extra-basinal colonization over time has fostered springsnail speciation, of which the Nevada and Utah assemblage provides one of the world's most prominent examples of biodiversity evolution in relation to environmental change.

Higher Taxonomy

Springsnails have a complex taxonomic history, one that is the subject of on-going research, with taxonomic advancement continuing at all systematics levels (Bouchet and Rocroi 2005, Ponder et al. 2008, Criscione and Ponder 2013, Hershler and Liu 2017, Lydyeard and Cummings 2019). These gastropods are a diverse and globally distributed group of small-bodied, aquatic families, including those in Nevada and Utah: Amnicolidae (*Amnicola* and *Coligyrus*), Assimineidae (*Assiminea*), Cochliopidae (*Eremopyrgus, Tryonia*), Hydrobiidae (*Pyrgulopsis*), Lithoglyphidae (*Fluminicola*), and Tateidae (non-native *Potamopyrgus*) in the superfamily Truncatelloidea (Hershler and Liu 2017); and Semisulcospiridae (Pleuroceridae;

Juga) in the superfamily Cerithioidea. Within the caenogastropod Littorinimorpha, Truncatelloidea was proposed to clarify relationships among a diverse array of species formerly assigned to the superfamilies of Rissoacea and Cingulopsoidea (Criscione and Ponder 2013). Representatives of this superfamily are known throughout the world (Table 2; e.g., Ponder et al. 1989).

Springsnail Species

A total of 103 Truncatelloidea and Semisulcospiridae springsnails species are considered in the Strategy, with 86 species documented in NV, 21 species in UT, and four species occurring in both states (Tables 3, 4; Fig. 1). All of the springsnail species recognized as occurring in the two states at the release of this version of the Strategy (1 September 2020) are included in this Strategy, and all have been recognized as valid species through rigorous morphological and genetic taxonomic classification efforts and scientific publications (Hershler and Liu 2017; Table 3; Appendix A). Nonetheless, research on species-level taxonomy is still underway, and the few widespread taxa typically have been, on closer investigation, subdivided into multiple haplotypes (subspecific lineages) or cryptic species. Thus, the Agreement list is likely to change based on improving taxonomy and future SCT considerations.

Below, we review the springsnail families of Assimineidae, Cochliopidae, Hydrobiidae, Lithoglyphidae, and Semisulcospiridae, which are the focus of this Strategy, and we mention other Mollusca taxa not considered here. The list of species (Table 3) includes the SSI taxon identity number (TID), the common and scientific name, and the state(s) in which the species occurs, the total number of surveys conducted on the species in the SSI database, the first and most recent survey date, the number of reported populations (primarily springs) at which the species has been detected. Information quality scores are summarized from the data presented and provide an inventory prioritization metric: species occurring at a low number of sites and which have not been recently surveyed warrant more immediate survey attention. Other data (i.e., elevation range (m), water quality requirements) are presented in Appendix A.
While springs, springsnail data, and information management are improving, much more remains to be learned about springsnails and their habitat and ecology. The information management system that supports the Strategy (Springs Online) has been refined to accommodate review and incorporate new information as it becomes available. Increased monitoring and taxonomic research will bring to light additional populations of springsnails, species not previously described or recognized, taxa previously considered to have been extirpated or, in contrast, taxa that may have passed into extinction. Following the family descriptions (below), we discuss other molluscan taxa that may be of conservation concern but are not presently considered in the Strategy. Due to the need for improved quality of information on distribution and conservation status, such species also may influence strategic conservation decision-making in the region.

Amnicolidae

Amnicolidae constitutes a family of small, gilled, operculate, freshwater snails in the order Littorinimorpha and superfamily Truncatelloidea that contains about 200 species worldwide (Bouchet and Rocroi 2005, Clark 2019a). Amnicolidae formerly was regarded as a subfamily of Hydrobiidae, but was distinguished as a distinct family by Hershler and Liu (2017). One of the

Table 3: Springsnails addressed in the Conservation Strategy for Springsnails in Nevada and Utah, including data from Springs Online on the species (reported by SSI-TID species number), the states of occurrence, the total number of NV-UT surveys conducted, the first and last known survey dates in Nevada or Utah, and the number of springs at which populations have been reported. Specific data on water quality requirements and conservation status are found in individual species accounts (Appendix A). Information quality scores, generally summarized from available information, provide an inventory prioritization metric.

SSI-TID	Scientific Name	Common Name	States of Occurrence	Survey count for NV and UT	First survey date detecting species	Last survey date detecting species	Total Spring Count for UT & NV	Springs location by land unit for UT & NV	Information quality score (Very Low, Low, Medium, Good, High)
15611	*Amnicola limosa*	Mud Amnicola	UT, E USA	1	4/30/1927	4/30/1927	1	State	Very Low
13385	*Assiminea infima*	Badwater Snail	CA, NV	7	8/20/1997	5/15/2014	2	NPS, BLM	Medium
13402	*Colligyrus greggi*	Rocky Mountain Duskysnail	ID,OR,UT,WA, WY	1	1999	---	1	Unknown	Very Low
6539	*Eremopyrgus eganensis*	Steptoe Hydrobe	NV	8	9/1/1980	6/14/2012	6	Private	Medium
13413	*Fluminicola coloradoensis*	Green River Pebblesnail	NV, UT, WY	11	1/1/1940	5/15/2014	11	Private, USFS, NPS	Medium
6540	*Fluminicola dalli*	Pyramid Lake Pebblesnail	NV	13	1/1/1992	7/15/2009	7	BLM	Medium
10699	*Fluminicola turbiniformis*	Turban Pebblesnail	CA, NV, OR	37	6/12/1991	4/17/2020	25	BLM, Private, FWS, USFS	High
6541	*Fluminicola virginius*	Virginia Mountains Pebblesnail	NV	4	8/11/1990	4/22/2001	2	BLM, Private	Low
13441	*Juga acutifilosa*	Topaz Juga	CA,NV, OR	10	1934	5/25/2019	8	BLM, USFS, Private	Good
6544	*Pyrgulopsis aloba*	Duckwater Pyrg	NV	7	9/3/1973	5/6/2009	6	Tribal, Private	Medium
6545	*Pyrgulopsis anatina*	Southern Duckwater Pyrg	NV	2	7/12/1994	10/17/2000	1	Tribal	Low
5749	*Pyrgulopsis anguina*	Longitudinal Gland Pyrg	NV, UT	34	6/23/1992	7/1/2016	21	Private	Good
6549	*Pyrgulopsis augustae*	Elongate Cain Spring Pyrg	NV	2	9/10/1991	10/13/2001	1	Private	Low

SSI-TID	Scientific Name	Common Name	States of Occurrence	Survey count for NV and UT	First survey date detecting species	Last survey date detecting species	Total Spring Count for UT & NV	Springs location by land unit for UT & NV	Information quality score (Very Low, Low, Medium, Good, High)
6550	*Pyrgulopsis aurata*	Pleasant Valley Pyrg	NV	5	9/7/1991	9/16/2008	4	Private	Low
6245	*Pyrgulopsis avernalis*	Moapa Pebblesnail	NV	62	1/1/1973	6/4/2016	26	FWS, Private, BLM	Good
6552	*Pyrgulopsis bacchus*	Grand Wash Springsnail	AZ, NV	1	5/6/2004	3/31/2017	1	State	Medium
6553	*Pyrgulopsis basiglans*	Large Gland Carico Pyrg	NV	6	7/24/1991	6/24/2009	3	BLM	Low
6555	*Pyrgulopsis bifurcata*	Small Gland Carico Pyrg	NV	3	7/24/1991	10/17/2000	1	Private	Low
6556	*Pyrgulopsis breviloba*	Flag Pyrg	NV	20	5/28/1972	7/2/2016	5	State, BLM, Private	Good
6557	*Pyrgulopsis bruesi*	Fly Ranch Pyrg	NV	4	2/8/1997	9/20/1997	2	Private	Low
6559	*Pyrgulopsis bryantwalkeri*	Cortez Hills Pebblesnail	NV	8	1/1/1912	5/10/2019	4	Private	Good
6561	*Pyrgulopsis carinata*	Carinate Duckwater Pyrg	NV	3	1/1/1998	1/1/2009	1	Unknown	Poor
6562	*Pyrgulopsis carinifera*	Moapa Valley Pyrg	NV	60	8/31/1973	6/4/2016	27	FWS, Private, BLM	Good
10728	*Pyrgulopsis chamberlini*	Smooth Glenwood Pyrg	UT	4	7/15/1993	9/5/2019	2	Private, State	Good
6243	*Pyrgulopsis coloradensis*	Blue Point Pyrg	NV	15	7/24/1988	1/19/2019	1	NPS	High
6565	*Pyrgulopsis cruciglans*	Transverse Gland Pyrg	NV	13	9/29/1989	6/15/2010	7	Private, BLM	Medium
5752	*Pyrgulopsis crystalis*	Crystal Springsnail	NV	6	6/25/1972	4/25/2008	1	FWS	Medium
13875	*Pyrgulopsis cybele*	Nature Pyrg	NV	2	6/2/2009	11/1/2010	2	BLM	Medium
4920	*Pyrgulopsis deaconi*	Spring Mountains Pyrg	NV	43	1/1/1975	5/12/2016	12	BLM, USFS, Private	Good
6569	*Pyrgulopsis deserta*	Desert Springsnail	UT	7	8/30/1973	5/22/2019	5	Private	Good

SSI-TID	Scientific Name	Common Name	States of Occurrence	Survey count for NV and UT	First survey date detecting species	Last survey date detecting species	Total Spring Count for UT & NV	Springs location by land unit for UT & NV	Information quality score (Very Low, Low, Medium, Good, High)
6571	*Pyrgulopsis dixensis*	Dixie Valley Pyrg	NV	5	9/8/1991	9/16/2008	3	BLM	Medium
5753	*Pyrgulopsis erythropoma*	Ash Meadows Pebblesnail	NV	24	1/1/1891	5/6/2012	9	FWS, BLM	Medium
5754	*Pyrgulopsis fairbanksensis*	Fairbanks Springsnail	NV	4	2/24/1978	6/29/2000	1	FWS	Low
6240	*Pyrgulopsis fausta*	Corn Creek Pyrg	NV	24	9/16/1975	9/20/2019	7	FWS	Good
10732	*Pyrgulopsis fusca*	Otter Creek Pyrg	UT	7	7/15/1993	7/3/2018	6	BLM, Private, USFS	Good
6576	*Pyrgulopsis gibba*	Surprise Valley Pyrg	CA, NV, OR	181	6/16/1988	10/11/2018	148	Private, BLM, USFS	High
6580	*Pyrgulopsis gracilis*	Emigrant Pyrg	NV	21	9/2/1973	6/7/2016	9	Private	Medium
10733	*Pyrgulopsis hamlinensis*	Hamlin Valley Pyrg	UT	9	6/23/1992	5/23/2019	8	Private, BLM	Good
15690	*Pyrgulopsis horseshutem* sp *1*	Horseshutem Pyrg sp. 1	NV	1	4/6/2013	4/6/2013	1	1623	Low
5755	*Pyrgulopsis hovinghi*	Upper Thousand Spring Pyrg	NV	3	9/18/1990	8/8/2013	1	BLM	Medium
6586	*Pyrgulopsis hubbsi*	Hubbs Pyrg	NV	23	9/9/1969	7/2/2019	5	Private	Good
6587	*Pyrgulopsis humboldtensis*	Humboldt Pyrg	NV	20	10/7/1990	11/2/2018	14	Private, BLM	High
6589	*Pyrgulopsis imperialis*	Kings River Pyrg	NV	19	1/1/1991	7/13/2018	13	Private, BLM	Good
10734	*Pyrgulopsis inopinata*	Carinate Glenwood Pyrg	UT	4	7/15/1993	9/5/2019	3	Private, State	Good
6591	*Pyrgulopsis isolata*	Elongate-gland Springsnail	NV	3	11/7/1985	6/29/2000	1	Private	Low

SSI-TID	Scientific Name	Common Name	States of Occurrence	Survey count for NV and UT	First survey date detecting species	Last survey date detecting species	Total Spring Count for UT & NV	Springs location by land unit for UT & NV	Information quality score (Very Low, Low, Medium, Good, High)
6592	*Pyrgulopsis kolobensis*	Toquerville Springsnail	NV, UT	441	5/12/1898	11/6/2019	342	Private, BLM, FWS, USFS, State, NPS, Tribal, BOR, DOD	High
6593	*Pyrgulopsis landyei*	Landyes Pyrg	NV	3	9/2/1980	10/18/2000	1	Private	Low
6594	*Pyrgulopsis lata*	Butterfield Pyrg	NV	16	9/2/1973	6/7/2016	8	Private, FWS, State	Good
6595	*Pyrgulopsis lentiglans*	Crittenden Pyrg	NV	7	8/19/1989	8/8/2013	3	Private	Low
6596	*Pyrgulopsis leporina*	Elko Pyrg	NV	9	7/30/1991	7/29/2008	5	Private	Low
13851	*Pyrgulopsis licina*	Curved Filament Pyrg	NV	16	11/11/1985	---	9	657 - 708	Very Low
5757	*Pyrgulopsis limaria*	Squat Mud Meadows Pyrg	NV	15	8/8/1991	9/8/2005	12	BLM, Private	Low
15481	*Pyrgulopsis lindahlae*	Lindahls Pyrg	UT	3	10/5/1976	5/21/2015	2	NPS	Medium
5758	*Pyrgulopsis lockensis*	Lockes Pyrg	NV	15	9/5/1973	6/13/2012	5	BLM, Private	Medium
6599	*Pyrgulopsis longiglans*	Western Lahontan Pyrg	NV	66	8/30/1979	7/30/2012	41	Private, BLM, USFS	Medium
6602	*Pyrgulopsis marcida*	Hardy Pyrg	NV	70	9/2/1973	8/28/2018	34	Private, BLM	Good
6603	*Pyrgulopsis merriami*	Pahranagat Pebblesnail	NV	29	7/20/1969	12/19/2018	12	BLM, Private	Good
5759	*Pyrgulopsis micrococcus*	Oasis Valley pyrg	NV	1	1/1/1900	2/15/2017	1	Private	Medium
5760	*Pyrgulopsis militaris*	Northern Soldier Meadow Pyrg	NV	9	6/3/1978	8/12/2013	2	Private	Medium
6605	*Pyrgulopsis millenaria*	Twentyone Mile Pyrg	NV	4	6/13/1989	9/16/2000	2	Private	Low

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6606	*Pyrgulopsis montana*	Camp Valley Pyrg	NV	2	6/24/1992	6/26/2001	1	Private	Low
5762	*Pyrgulopsis nanus*	Distal-gland Springsnail	NV	14	3/2/1971	4/23/2008	9	FWS, Private, BLM	Medium
6610	*Pyrgulopsis neritella*	Neritiform Steptoe Ranch Pyrg	NV	3	9/2/1980	10/18/2000	1	Private	Low
6611	*Pyrgulopsis nevadensis*	Corded Pyrg	NV	7	1/1/1883	1/1/1962	2	BLM, Tribal	Very Low
10736	*Pyrgulopsis nonaria*	Ninemile Pyrg	UT	3	7/15/1993	1/1/1998	3	Private	Low
5764	*Pyrgulopsis notidicola*	Elongate Mud Meadows Pyrg	NV	19	8/30/1979	6/6/2018	8	BLM, Private	Good
15353	*Pyrgulopsis nuwuvi*	Nuwuvi Pyrg	UT	2	11/13/1984	9/5/2016	1	USFS	Medium
6614	*Pyrgulopsis orbiculata*	Sub-globose Steptoe Ranch Pyrg	NV	3	9/1/1980	11/21/1995	2	Private	Very Low
6618	*Pyrgulopsis papillata*	Big Warm Spring Pyrg	NV	11	9/3/1973	6/16/2010	3	Tribal, Private	Medium
6620	*Pyrgulopsis peculiaris*	Bifid Duct Pyrg	UT	46	8/6/1991	7/1/2016	25	BLM, USFS, Private	Good
6621	*Pyrgulopsis pellita*	Antelope Valley Pyrg	NV	3	6/8/1991	7/6/2001	1	Private	Very Low
6623	*Pyrgulopsis pictilis*	Ovate Cain Spring Pyrg	NV	2	9/10/1991	10/31/2001	1	Private	Very Low
6624	*Pyrgulopsis pilsbryana*	Bear Lake Springsnail	UT	4	7/19/1993	7/19/1993	4	Private	Very Low
15355	*Pyrgulopsis pinetorum*	Pine Grove Pyrg	UT	5	2/17/1977	10/6/2016	5	USFS, Private	Good
5767	*Pyrgulopsis pisteri*	Median-gland Springsnail	NV	14	11/9/1985	5/5/2012	5	FWS	Medium
6626	*Pyrgulopsis planulata*	Flat-topped Steptoe Pyrg	NV	8	6/23/1992	6/14/2012	4	Private	Low
10738	*Pyrgulopsis plicata*	Black Canyon Pyrg	UT	1	7/14/1993	7/14/1993	1	BLM	Very Low

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6629	*Pyrgulopsis ruinosa*	Fish Lake Valley Pyrg	NV	3	6/16/1988	1/1/1992	2	BLM, Private	Very Low
6630	*Pyrgulopsis sadai*	Sadas Pyrg	NV	33	6/22/1991	8/11/2013	15	BLM, Private	Good
13850	*Pyrgulopsis sanchezi*	Sanchez Pyrg	NV	$\geq$3	2/26/1985	11/14/2012	16	650 – 720	Medium
15356	*Pyrgulopsis santaclarensis*	Santa Clara Pyrg	UT	5	9/2/1980	10/6/2015	2	USFS	Good
6631	*Pyrgulopsis sathos*	White River Valley Pyrg	NV	36	5/28/1972	7/3/2016	16	Private, State, BLM	Good
10740	*Pyrgulopsis saxatilis*	Sub-globose Snake Pyrg	UT	9	5/10/1993	5/28/2019	3	BLM	Good
6633	*Pyrgulopsis serrata*	Northern Steptoe Pyrg	NV	42	8/7/1988	7/13/2018	33	Private, BLM	Good
6637	*Pyrgulopsis sterilis*	Sterile Basin Pyrg	NV	12	10/2/1992	7/1/2020	6	Private, BLM, USFS	High
6638	*Pyrgulopsis sublata*	Lake Valley Pyrg	NV	9	6/26/1992	7/2/2016	4	Private	Medium
6639	*Pyrgulopsis sulcata*	Southern Steptoe Pyrg	NV	11	8/5/1991	6/14/2012	5	Private	Medium
10744	*Pyrgulopsis transversa*	Southern Bonneville Pyrg	UT	11	5/11/1993	8/26/1993	11	Private, State, BLM, USFS	Very Low
6242	*Pyrgulopsis turbatrix*	Southwest Nevada Pyrg	CA, NV	83	3/2/1972	6/3/2016	22	BLM, Private, USFS, DOD	Good
5770	*Pyrgulopsis umbilicata*	Southern Soldier Meadow Pyrg	NV	15	6/3/1978	9/8/2005	8	BLM, Private	Medium
6645	*Pyrgulopsis variegata*	Northwest Bonneville Pyrg	NV, UT	23	8/30/1992	8/8/2013	17	BLM, Private, USFS	Medium

SSI-TID	Scientific Name	Common Name	States of Occurrence	Survey count for NV and UT	First survey date detecting species	Last survey date detecting species	Total Spring Count for UT & NV	Springs location by land unit for UT & NV	Information quality score (Very Low, Low, Medium, Good, High)
10745	*Pyrgulopsis varneri*	Varners Pyrg	NV	18	8/8/1991	9/28/2011	9	BLM, Private	Medium
6646	*Pyrgulopsis villacampae*	Duckwater Warm Springs Pyrg	NV	10	9/3/1973	6/16/2010	2	Tribal	Medium
6647	*Pyrgulopsis vinyardi*	Vineyards Pyrg	NV	11	1/1/1992	8/11/2018	10	Private	Medium
6648	*Pyrgulopsis wongi*	Wongs Springsnail	CA, NV	36	1/1/1989	7/12/2018	18	USFS, BLM, Private	Good
5783	*Tryonia angulata*	Sportinggoods Tryonia	NV	15	11/22/1969	4/25/2008	3	FWS, BLM	Medium
6247	*Tryonia clathrata*	Grated Tryonia	NV	92	8/31/1973	6/8/2016	39	FWS, BLM, NV,Private, Tribal	Good
5786	*Tryonia elata*	Point of Rocks Tryonia	NV	6	11/8/1985	10/1/1993	3	FWS, BLM	Very Low
5787	*Tryonia ericae*	Minute Tryonia	NV	5	11/9/1985	10/1/1993	3	FWS	Very Low
13873	*Tryonia infernalis*	Blue Point Springs Tryonia	NV	1	Many-NPS	Many-NPS	1	NPS	High
6665	*Tryonia monitorae*	Monitor Tryonia	NV	13	1/1/1992	8/1/2009	5	Private	Low
10762	*Tryonia porrecta*	Desert Tryonia	CA, NV	24	8/26/1927	12/13/2018	21	FWS, State, Private, DOD, USFS, NPS	High
5792	*Tryonia variegata*	Amargosa Tryonia	NV	63	11/23/1969	6/13/2017	25	FWS, Private, BLM, NPS	Good

Table 4: Summary of springs and springsnail distribution and inventory history in Nevada and Utah. Data summarized from Springs Online as of 1/1/ 2020.

Variable State:	Nevada	Utah	Total
No. Reported Springs on Federal Land	17,835	6,129	23,964
No. Inventoried Springs on Federal Land	2,610	832	3,442
No. Springs on State or City Land	280	603	883
No. Inventoried Springs on State or City Land	12	43	55
No. Springs Tribal Land	133	354	487
No. Springs Inventoried on Tribal Land	20	2	22
No. Springs on Private Land	7,221	4,559	11,780
No. Springs Inventoried on Private Land	761	186	947
Total No. Reported Springs	**25,469**	**11,645**	**37,114***
Total No. Inventoried Springs	**3,403**	**1,063**	**4,466**
No. Federally-owned Springs with Springsnails	399	116	515
No. State- or City-owned Springs with Springsnails	5	32	37
No. Tribally-owned Springs with Springsnails	11	1	12
No. Privately-owned Springs with Springsnails	365	164	529
Total No. Springs with Springsnails	**780**	**313**	**1,093**

Additional springs and inventories have been added and conducted during preparation of this document, and the total number of springs is now at least 37,121 springs.

two amnicolids is reported in Nevada and/or Utah, the mud amnicola (*Amnicola limosa).* Mud amnicola reportedly occur widely along the northeastern coast of North America, and is known historically from four counties in Utah. However, mud amnicola populations in Utah no longer exist at the historical sites it formerly occupied and the species appears to have been extirpated from Utah (Taylor and Bright 1987, Oliver and Bosworth 1999). The other amnicolid in the region is the Rocky Mountain duskysnail (*Colligyrus greggi*), reported from Utah by Hershler (1999) in Hershler and Liu (2017), from a population discovered by Don Sada in 1993 at a single springs ecosystem, reporting it as being common there at the time of discovery.

Assimineidae

The assimineids are minute, aquatic, operculate truncatteloidean springsnails, with rudimentary cephalic tentacles, a grooved foot, and a trunk-like snout, and sometimes missing the ctendidium respiratory apparatus. This family occurs in saline waters, and some species are marine (Fukada 2019). Only a single species, the Badwater snail (*Assiminea infima*) occurs in a single springs ecosystem in Nevada and several springs in Death Valley National Park, California.

Cochliopidae

Members of this family of springsnails are small, live-bearing aquatic springsnails (Clark 2019b). The most prominent genus in the family is *Tryonia*, which is characterized by relatively narrow-elongate shells, and papillac-like penial lobes. It is well-represented in Nevada, with eight species reported, while con-familial *Eremopyrgus* is represented only by the Steptoe hydrobe (*E. eganensis*). As in other springsnail families, Cochliopidae biodiversity is highly threatened by human activities. Hershler et al. (2011) reported that two of 19 (10.5%) North American *Tryonia* species have passed into extinction in the past several decades. The extant taxa are primarily local endemics. A concise review of the Cochliopidae and its distribution in the western hemisphere, the Mediterranean and southern Africa is provided by Clark (2019b).

Hydrobiidae

These aquatic gastropods are known as mudsnails, springsnails, and pyrgs. Hydrobiidae is a large, cosmopolitan family with a fossil record extending back to the Mississipian Period more than 300 million years ago (Hershler and Liu 2017). Hydrobiid taxonomy has undergone a complex history over the past two centuries. Hershler and Thompson (1987), followed by Kabat and Hershler (1993) summarized the taxonomic relationships among hydrobiids and related truncatelloidean taxa. Those and subsequent studies have clarified taxonomic affiliations among many truncatelloidean taxa (Hershler et al. 2013, 2014a, 2014b, 2016a; summarized in Hershler and Liu 2017; Wilke and Delicado 2019). This family presently is placed in the order Littorinimorpha and is a large family in the superfamily Truncatteloidea. Ten genera have been assigned to Hydrobiidae, and the family may include 1,000 or more species globally, and at least 139 North American species have been described thus far (Hershler and Liu 2017). The family was originally described by Troschel in 1857 as the group Hydrobiae, but Troschel was uncertain as to its taxonomic status, placing it in the Taenioglossata: Ctenobranchiata between the Lithoglyphi and Ancyloti. Generic revision within the family in the latter half of the 20th Century transferred some species in the genus *Fluminicola* into *Pyrgulopsis* and removed the genus *Tryonia* to the family Cochliopidae (Hershler and Liu 2017; Wilke and Delicado 2019).

Pyrgulopsis Call and Pilsbry (1886) is a species-rich genus of hydrobiid springsnails. *Pyrgulopsis* is found throughout western North America (Hershler et al. 2013, 2014a; Hershler and Liu 2017). Molecular studies reveal that several of the more widely distributed members of this genus are composites of divergent lineages. North American hydrobiid shell heights often are <3 mm. The dextrally (right)-coiled shells are smooth (except for growth lines conforming to the shape of the outer lip) and, while elegant, are usually rather nondescript, offering few clear characteristics for taxonomists to classify species within this family. This difficulty is compounded by a high degree of intraspecific variation. Species descriptions often are based on the characteristics of the operculum, radula, and penis, but genetic analyses recently have provided profound insight into taxonomy and distribution. As an example of complicated taxonomy, the Moapa Pebblesnail (*Pyrgulopsis carinifera* (Pilsbry 1935)] was originally described as *Fluminicola avernalis carinifera* by Pilsbry (1935) in the family Flumincolidae. Fluminicola was subsumed into Lithoglyphidae by Hershler and Liu (2017), but *F. a. carinifera* was elevated to species level in *Pyrgulopsis* in Hydrobiidae. Such taxonomic changes are anticipated as new populations and taxa are discovered, and additional genetic analyses are conducted. At present, 86 *Pyrgulopsis* species are included in the Nevada and Utah list.

Lithoglyphidae

Hershler and Liu (2017) subsumed most of the Fluminicolidae into the Lithoglyphidae (Fluminicolidae had previously been considered a subfamily within Hydrobiidae). This family was recently reviewed by Clark (2019c). Like hydrobiids, these are tiny aquatic snails, requiring clear water and firm substrata at and near the sources of springs. A total of four *Fluminicola* species are included on the Nevada and Utah list.

Semisulcospiridae (Pleuroceridae, in part)

This family of small to intermediate-sized Neotaenioglossa freshwater snails is characterized by a tightly coiled, high-spired shell, and by having gills and an operculum (Strong and Ledyeard 2019).Springsnails in the genus *Juga* typically are found in clear, permanent springs, creeks and rivers, especially on firm substrata. They are regarded as being intolerant of excessive sedimentation and are absent from impoundments and other still water habitats, such as ponds. These microhabitat habitat preferences indicate that the reports of supposedly wide-ranging species may be incorrect. Most taxa from the Pit-Sacramento River system in California are endemic, although a few taxa extend into adjacent parts of the Klamath River basin or the Great Basin, but not further (Campbell et al. 2016).

Although *Juga* is difficult to separate from genera such as the pleurocerid *Elimia* in eastern North America based on shell characters, it can be distinguished by anatomical and reproductive tract differences (Graf 2001). Both *Juga* and *Semisulcospira* possess a seminal receptacle, unlike eastern North American Pleuroceridae (Prozorova 1990, Strong 2005). Differences in the reproductive tract also lead to differences in egg mass morphology. Molecular and morphological data support the affinity of *Juga* with the Asian genera *Hua*, *Koreoleptoxis* and *Semisulcospira* (Strong and Frest 2007, Strong and Whelan 2019).

Juga formerly was placed in the cerithioidean pleurocerid subfamily of Semisulcospirinae, a subfamily elevated to familial rank by Strong and Köhler (2009), and within-genus taxonomy is under debate (Strong and Ledyeard 2019). Three *Juga* species were previously recognized in western Nevada: 1) topaz Juga (*Juga acutifilosa*), found in California, Nevada, and Oregon springs; 2) smooth juga (*J. interioris*), which retained its taxonomic status through a genomic review in relation to *J. hemphilli* and the eastern genus *Elimia* (Lee et al. 2006); and 3) oasis juga [*J.* (*Goniobasis*) *laurae* Goodrich 1944)] based on specimens collected by Carl Hubbs in 1934 in Boulder Springs and at an unnamed spring west of Home Camp in Long Valley, Washoe County, Nevada, as well as from springs in Grasshopper Valley, Lassen County, California.

The diversity of *Juga* taxa in Nevada is likely lower than is presently recognized (Strong 2005, Strong and Frest 2007, Strong and Köhler 2009, Strong 2019, Strong and Lydeard 2019, Strong and Whelan 2019), and current molecular research suggests the need for systematic revision. Specimens collected in northwestern Nevada from Bitner Ranch, Divine Spring and Murrer's Meadow, the type localities for smooth juga, oasis juga, and topaz juga, all have less than one percent uncorrected pairwise divergence in mitochondrially encoded cytochrome c oxidase I (MT-CO1), and less than one percent compared to samples from Coleman Lake in southeastern Oregon. Recent analyses of the topaz juga group (Clade 9; combining topaz, smooth, and oasis jugas) from northern California, southeastern Oregon, and northwestern Nevada, indicate that smooth and oasis Jugas should be synonymized within topaz juga. Therefore, only the topaz juga has been included in the Agreement list (Table 3, Appendix A).

Other Mollusca

The Strategy focuses conservation attention on extant springsnail species in Nevada and Utah; however, several aquatic springsnails that are presumed extirpated or extinct also warrant SCT management attention. Presumed extirpated or extinct springsnail taxa in Nevada and Utah include corded pyrg (*Pyrgulopsis nevadensis*), Fish Lake pyrg (*P. ruinosa*), and Rocky Mountain duskysnail. However, their extinction has not been proven and inventories have been conducted only on a small percentage of Nevada and Utah springs. Further exploration may reveal hitherto unknown populations of those species, so the declaration of their extinction may be premature. The SCT recommends that all such species be retained on the Strategy list so that if new populations are discovered they will swiftly be included in conservation planning. Continued inventory for these taxa is warranted.

A similar scenario occurred with relict leopard frog (Ranidae: *Lithobates onca*) in southern Nevada, which was considered to be extinct but was re-discovered at springs along the western margin of Lake Mead (Relict Leopard Frog Team 2016). Because the period for state and federal recognition of such re-discovered populations may be protracted, it is prudent to include extinct species on the list to ensure prompt attention if populations are re-discovered.

Other native aquatic Mollusca taxa that have not been included in this Strategy include members of the family Lymnaeidae (e.g., *Fossaria*; Johnson et al. 2013), likely extinct *Stagnicola utahensis* (Stein et al. 2000), and species in the family Physidae, such as the extant wet-rock physa or Zion snail (*Physella zionis*; endemic to springs and streams in Zion National Park, Utah) and the possibly extinct *Physella microstriata* (Oliver and Bosworth 1999, Stein et al. 2000, Hovingh 2018). In addition, several bivalve species are rare or poorly known in Nevada and/or Utah, including floater mussels (*Anodonta* spp.) and pea clams (Sphaeriidae: *Pisidium* spp.). Besides aquatic gastropod taxa, several terrestrial wetland snail taxa (e.g., Succineidae: *Oxyloma*) are not presently included in the Agreement, and may warrant attention.

3. Geography and Landscape Context

Nevada and Utah Geography

The region encompassed in this plan includes the states of Nevada and Utah (Figs. 1, 2). Internally-draining Nevada rivers include the Amargosa, Truckee, Carson, Walker, and Humboldt rivers in the south, west, and northern parts of the state. Externally draining Nevada rivers include the White/Muddy, Colorado, and Virgin rivers in the southeastern portion of the state, and the Snake and Owyhee rivers in the northern and northwestern portions of the state. Utah's portion of the region is drained by: the endorheic Bonneville Basin drainages in the western half of the state; the endorheic Sevier River in the central southwestern portion of the state; the exorheic Colorado River basin in the east and south; the Virgin River in the Lower Colorado Region to the south, and tributaries of the Snake River in the Pacific Northwest Region to the north. Past surface drainage and aquatic habitat connectivity has permitted springsnail gene flow and population establishment among some of these fluvial systems (e.g., Hershler 1989, Hershler and Liu 2008).

The Basin and Range geologic province dominates the western two thirds of the Nevada and Utah study area. The Basin and Range province extends from southeastern Oregon, south and southeastward through eastern California, including all of Nevada, the western half of Utah, the southern halves of Arizona and New Mexico, southwestern Texas, and northern Mexico. With a geologic history extending back to Archean time, this vast region has been

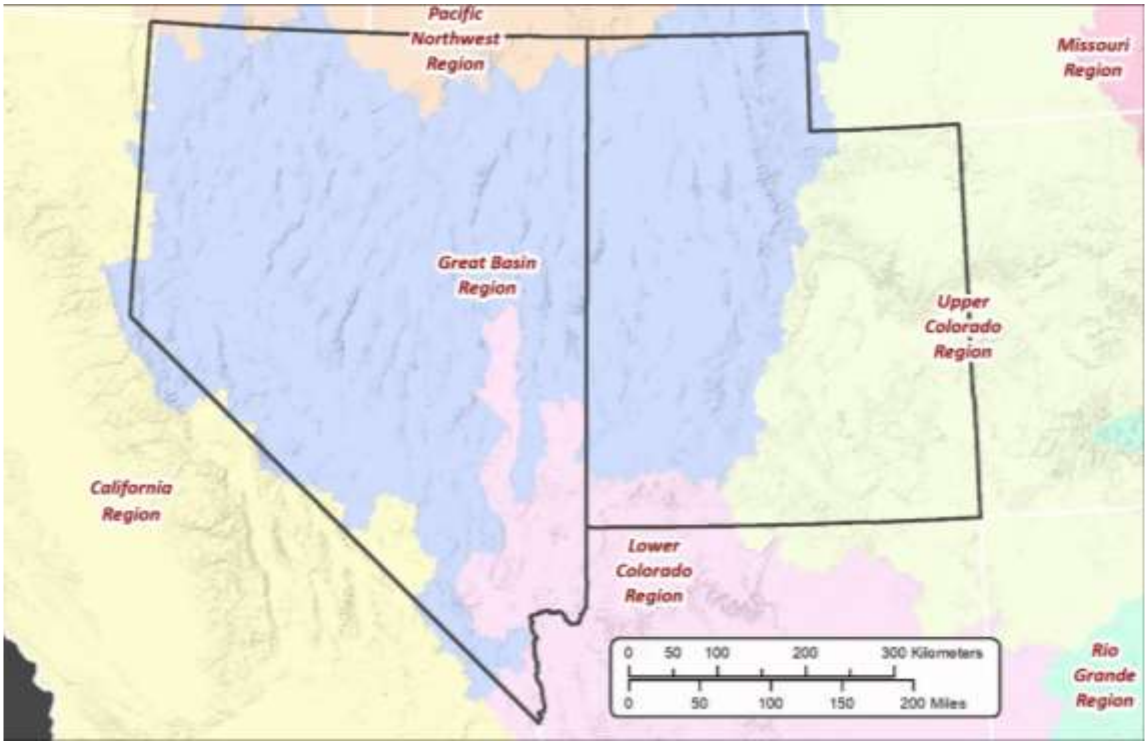

Figure 2: Geologic regions of Nevada and Utah. The Great Basin is shown in blue and the lower Colorado River basin is shown in pink.

undergoing tectonic extension over the past 20 million years. As the Earth's crust is being gradually stretched apart, horst (uplifted) mountain ranges with intervening graben (downthrown) valleys have developed across the landscape (Dickinson 2006). The Great Basin portion of the Basin and Range province in Nevada and Utah drains internally (endorheic drainage), whereas other portions of the province are drained by rivers that, at least historically, reached the sea (e.g., the Colorado and Rio Grande rivers). Geologically, the Great Basin also is renowned for its large, endorheic Pleistocene lakes. As recently as 15,000 year ago, such lakes included the 1,600 km^2 Lake Manly in the Amargosa River and Death Valley drainages, the 22,000 km^2 Lake Lahontan in northwestern Nevada, and the 51,000 km^2 Lake Bonneville in Utah (e.g., Benson and Thompson 1987, Hershler and Liu 2008). Those, and other Pleistocene lakes in the Southwest waxed and waned with changing climate over the past two million years and influenced the evolutionary radiation of springsnails and other aquatic biota.

Climate

The weather of Nevada and Utah is continental and arid, with hot dry summers and wetter winters. Nevada and Utah are the first and third driest states in the nation, respectively. Elevation strongly influences ambient temperature, with low deserts in southern Nevada and Utah sustaining high temperatures in excess of 50°C and high elevations in the north with winter low temperatures below -20°C. Precipitation is similarly influenced by elevation, with low deserts sometimes receiving less than 75 mm/year, and high elevations in the north receiving much more than 1,000 mm/year. Precipitation is moderately to strongly bimodal in the southwestern portion of the region, with intense summer monsoonal rains arriving from the south, while winter is the dominant season for precipitation in the northern portions of Nevada and Utah.

Springsnails typically occupy elevations below 2,300 m, thus the ambient climate of their habitats is typically warm and summer-dry; however, the Wasatch Front near Salt Lake City, receives more moisture than other low elevation areas in the two states, and the Wasatch Front supports many populations of springsnails.

Land Management

Most of the area of concentration is managed by federal agencies, with an emphasis on agricultural and mining uses, and some lands managed by Native American Tribes. The major cities in the Strategy area include Las Vegas, Reno, and Salt Lake City; however, there is relatively little private or state land in the region. The three cities are placing increasing demands on the region's limited water supplies. Sustainable water resource development calls for consideration of conservation priorities, which is the focus of this Strategy.

Springs Ecosystems

Springs and Springsnail Distribution

Springs occur where groundwater is exposed at, and usually flows from, the Earth's surface (Springer and Stevens 2009). Nevada, the nation's driest state, presently is recognized as having the highest density of springs in the USA (Fig. 1), with an estimated 27,000 springs (0.1 springs/km^2; MNA-SSI 2019). Utah also supports a high density of springs, with at least 10,121 springs reported. In all, these two states are reported to contain at least 37,121 springs. Of those, 4,466 (12%) springs have been inventoried (some multiple times), for a total of 6,287 inventories. Springsnails have been detected at least at 1,093 springs in the two states. If the current state of knowledge can be extrapolated to future springsnail detections, springsnails may exist at >9,400 springs in the two states. Thus, accomplishing a thorough springsnail inventory across the entire region will require an organized and concerted effort over at least the next decade, not to mention collaboration with taxonomic and habitat experts as well as consistent, regularly updated information management to track populations and springs ecosystem status.

Hydrology

***Overview*:** The Great Basin portion of this landscape has been a focus of considerable regional groundwater and surface water hydrological research, and both public and political attention. Nearly all of Nevada and the western half of Utah fall into the Basin and Range geologic province, while the major surface drainages around the Great Basin include the Colorado River basin (the eastern half of Utah), the Amargosa and Sevier river basins (southwestern Nevada and Utah, respectively), and the Snake and Owyee river basins (Pacific Northwest and parts of northern Nevada and Utah; Figs. 1, 2). Colorado River water from Nevada and Utah is exported to Denver, Phoenix, Tucson, Las Vegas, Los Angeles, and San Diego, as well as through many irrigation operations both in and outside the Colorado River basin; however, more than 50% of the Colorado River's surface flow is derived from groundwater (Stevens et al. 2020).

Great Basin: Local and regional groundwater is derived from precipitation, which infiltrates into subsurface strata. The percent of incoming precipitation that infiltrates and recharges aquifers is strongly dependent on elevation, ranging from 0 percent at low elevations that receive $\leq$203 mm of annual precipitation up to 25 percent at high elevations, which can receive >490 mm of annual precipitation (Masbruch et al 2011).

Groundwater is geographically distributed among four Nevada and Utah groundwater flow systems (Heilwell and Brooks 2011; Fig. 2), including drainages into the Great Salt Lake Desert/Lake Bonneville basin, the Humboldt River/Lahontan basin, the Colorado River basin, and the Death Valley/Lake Manly basin, each of which is subdivided into major sub-basins and a great many local aquifers (e.g., Prudic et al. 2015; Figs. 2, 3a-d). Much of the Great Basin portion of the Strategy study region is underlain by the 285,000 km^2 Great Basin carbonate and alluvial aquifer system (GBCAAS). Some GBCAAS sub-basins extend beneath several endorheic valleys, producing springs with flow paths hundreds of kilometers in length and groundwater residence times in excess of 10,000 years (e.g., the White-Muddy River drainage in eastern Nevada; Winograd et al. 1992, Thomas and Mihevc 2011).

Understanding groundwater hydrology, supplies, and risk assessment can be advanced through conceptual, numerical, and other flow models that incorporate climate, aquifer hydrogeology, anthropogenic withdrawal, and other factors. The GBCAAS has been intensively studied and modeled by the U.S. Geological Survey and the Department of Defense (e.g., Harrill and Prudic 1998; summarized by Wittmeyer 2017). For example, Prudic et al. (1995) developed a numerical flow model for much of the GBCAAS using a 259,000 km^2 study area that extended from the Wasatch Front to Death Valley, but excluding the Snake River drainage in northern Nevada and Utah. Such models can clarify aquifer boundaries, integrate far-field (non-local) hydrology, and may identify groundwater withdrawal hotspots, Pleistocene aquifers, and other hydrologic features. However, some hydrologists emphasize that such models are of limited use in risk assessment at the scale of individual springs.

At finer spatial scales, thousands of montane groundwater basins with shorter flow paths exist in hundreds of mountain ranges and support thousands of springs throughout Nevada and Utah (e.g., Fig. 3d). Although such montane groundwater basins are relatively small and rarely modeled, their springs sometimes are of considerable interest and value, and those at lower elevations may support springsnails. Prudic et al. (2015) describe a small mountain-valley groundwater basin in Great Basin National Park.

Colorado River Basin: The Colorado River is among the most heavily regulated rivers in the world, with a dozen large federal dams and many smaller dams and diversions throughout the basin providing water and hydroelectric power to downstream urban areas (i.e., Las Vegas, Phoenix, Tucson), and also for metropolitan areas lying outside the basin, including Denver, Fort Collins, south-central Colorado, Salt Lake City, Los Angeles, and San Diego (US Bureau of Reclamation 2012). The Colorado River basin is divided by the 1922 Colorado River Compact at Lee Ferry in northern Arizona, with the upper basin (UCRB; Colorado, New Mexico, Utah, and Wyoming) lying primarily on the Colorado Plateau, and the lower basin (LCRB; Arizona,

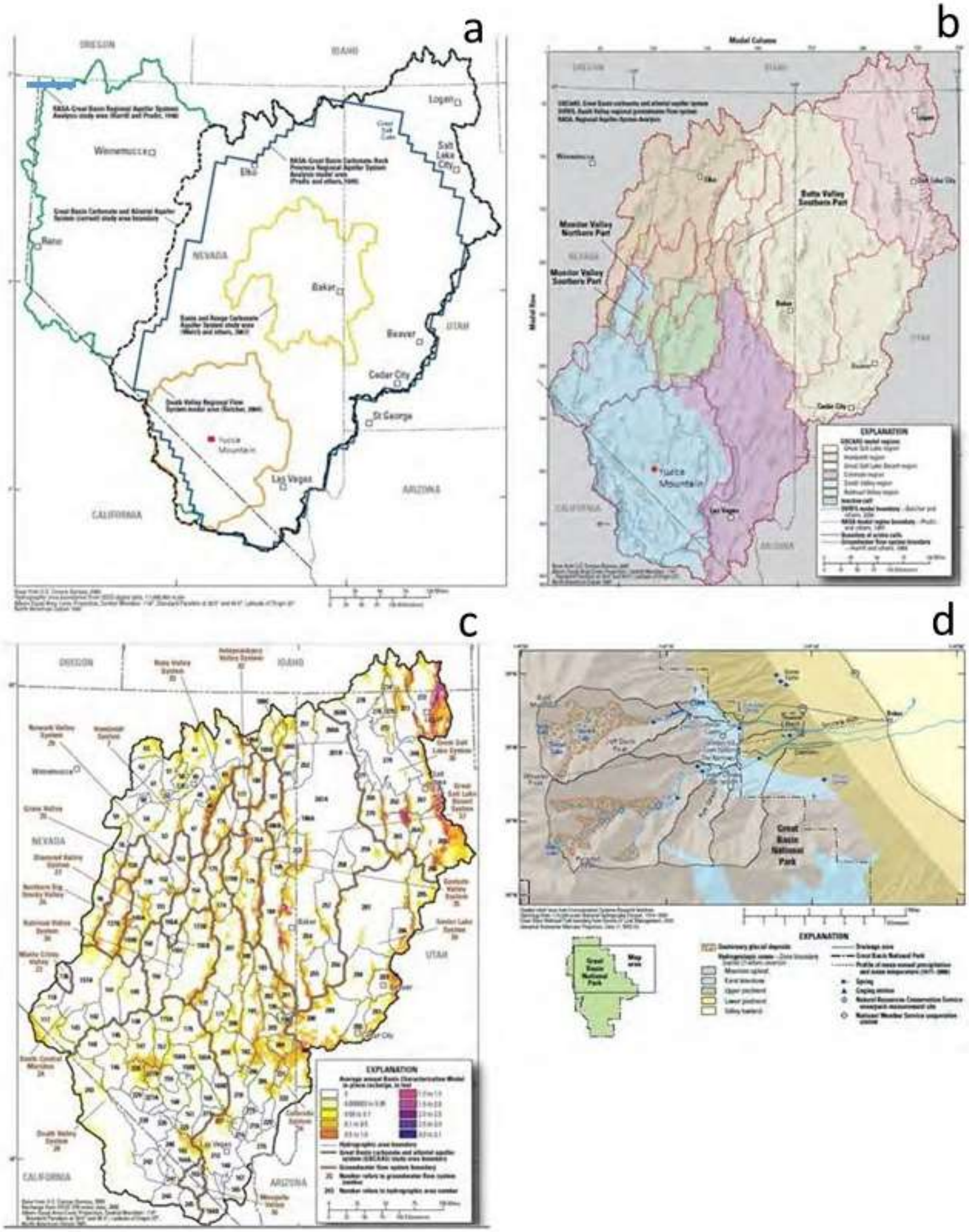

Figure 3: Nevada and Utah groundwater basin boundaries across spatial scale: a) Basin-wide (Prudic et al. 1995), b) among major sub-basins, c) among 8-digit hydrologic unit code sub-basins, and d) an example of fine-scale hydrology in eastern Great Basin National Park (Prudic et al. 2015, Wittmeyer 2017).

California, and Nevada) occupying the Basin and Range geologic province (Stevens et al. 2020). Most of the river basin's discharge is derived from the UCRB Green and upper Colorado rivers. Water delivery is coordinated by the Department of the Interior, with water management facilities managed by the US Bureau of Reclamation. Hydroelectric power management and delivery is coordinated by the US Department of Energy Western Area Power Administration. Needless to say, the Colorado River basin's surface water hydrology has received intensive study due to its importance in providing water for many large southwestern metropolitan areas, as well as water delivery for irrigated agriculture. An extensive analysis of discharge in response to climate change was conducted by US Bureau of Reclamation (2012).

As in the Basin and Range geologic province, most incoming precipitation is lost to evapotranspiration and little is available for infiltration into the region's aquifers. Nonetheless, springs and springs-dependent taxa abound in the Colorado River basin. Stevens et al. (2020) estimated that approximately 22,000 springs exist in the Colorado River basin, and documented the presence of at least 330 SDT of plants, invertebrates, fish, and herpetofauna, as well as several mammals and one bird species. However, they warn that the Colorado is a river in transition, changing from surface flow dominance to groundwater-dominance, a phase change that, in the context of climate change and largely unregulated groundwater depletion, will eventually transition to further dewatering of springs as well as mainstream channel segments. With regard to springsnails, they highlight the lower diversity of aquatic gastropods on the Colorado Plateau where only eight springsnail taxa occur, in comparison with conspicuous species richness of springsnails in the Basin and Range geologic province.

Pacific Northwest Snake River Drainages: The Owyhee and upper Snake Rivers drain portions of the northern and northwestern counties of Nevada and Utah, respectively. Overflow of the Great Salt Lake through Red Rock Pass in northwestern Utah resulted in dewatering of that great Pleistocene water body (O'Connor and Costa 2004). These remote Snake River drainage subbasins are dominated by late Tertiary basalts, which are important aquifers, and produce a relatively high density of springs. However, as elsewhere, comparatively few of those springs have been inventoried, and much remains to be learned about their springs ecohydrology and about springsnails and other springs-dependent taxa. While Snake River drainages make up only a small portion of some of the northern tier of counties in the two states, the two drainages support springsnail species not found elsewhere. For example, nature pyrg (*Pyrgulopsis cybele)* are found only in several springs in the upper Owyhee drainage in northwestern Nevada (Hershler and Liu 2012).

Springs Ecosystem Types

Springer and Stevens (2009) and Stevens et al. (in press) identified 12 primary types of terrestrial springs ecosystem, all of which occur in Nevada and Utah. These include: cave springs, bedrock exposure springs, artesian fountains, thermal or gas-driven geysers, cliff-emerging gushets, hanging gardens, wet meadow helocrenes, hillslope springs, desiccating hypocrenes, pool- forming limnocrenes, carbonate or organic mound-forming springs, and in-channel rheocrenes (MNA-SSI 2019). Springsnails have been detected at nearly all of these springs types, and from cold to warm, valley floor to upland hillslope springs, and in rheocrene, limnocrene, and precipitate mound springs types.

Springs Ecohydrology

Nevada and Utah springs that support springsnails are generally perennial and constant environments, but collectively range widely in hydrogeological context, type, landscape setting, size, water quality, and biogeographic history (Myers and Resh 1999, USFWS 2017). The innumerable combinations of these variables make springs ecosystems highly individualistic (Stevens 2020). Due to the often highly arid conditions of the adjacent uplands in Nevada and Utah, many springs exhibit steep gradients of moisture and nutrient availability, soils, and productivity, all of which decrease sharply outside the wetted perimeter of the springs ecosystem. Because of multiple, steep ecological gradients at springs, some researchers consider springs to be ecotones (spatially discrete environmental transition zones; Stevens 2020). Springsnails and other springs-dependent species often are specifically adapted to these gradients, and cannot exist outside of their individual springs ecosystem. Individual springs often support unique assemblages of species, thus having high (internal) beta-biodiversity, while all springs in a landscape collectively contribute to high (among-springs) gamma-diversity.

Springsnails generally occur in perennial springs, and the presence of springsnails, particularly endemic species, often indicates that the spring flow has been perennial because springsnail populations cannot persist when springs ecosystems dry out. Thus, springsnails are not found at ephemeral springs. Springsnails also occur in settings that are not highly disturbed by flooding, trampling, or other forms of regular disturbance. However, Kodrick-Brown and Brown (2007) and Stevens et al. (2016) indicate that some disturbance generally is necessary to maintain the presence of open water at desert springs. For example, Grand Canyon Wildlands Council (2002) attributed the extirpation of a population of Grand Wash springsnail (*Pyrgulopsis bacchus*) to fencing that excluded livestock grazing from a springs ecosystem in northwestern Arizona. Wetland and riparian vegetation inside the exclosure grew so profusely that it eliminated surface water, thereby eliminating springsnail habitat. Frequent use and alteration of springs by Pleistocene megafauna and humans throughout the arid Southwest since late Pleistocene time may have reduced springs vegetation cover around many springs. Kodrick-Brown and Brown (2007) concluded that appropriate springs stewardship requires careful planning to maintain an appropriate level of habitat disturbance to ensure the continued presence of open water.

Ecological Characteristics of Springs

Nevada and Utah springs are renowned hotspots of biological diversity. They protect a wide array of endemic, rare, and endangered species and, as refugia, warrant conservation attention (Noss 2000; Stevens and Meretsky 2008; Abele 2011). Springsnails are among several taxa of management concern in Nevada and Utah springs, with other taxa including: wetland plants; naucorid and belostomatid water bugs (Hemiptera); aquatic beetles; pupfish and splitfin/poolfish (*Cyprinodon* spp., *Empetrichthys* spp., respectively), and other fish; relict leopard frog (*Lithobates onca*; Relict Leopard Frog Conservation Team 2016) and other amphibians; and voles (*Microtus* spp.). Other poorly known or undescribed, but likely locally endemic springs taxa in Nevada and Utah springs include: flatworms (Turbellaria); microcrustaceans (e.g., ostracoda, cladocerans, copepods); water mites (Acarini); Physidae and other aquatic snails; pea clams (Sphaeriidae); land snails (e.g., Succineidae); mayflies

(Ephemeroptera); dragonflies (Odonata); stoneflies (Plecoptera); dytiscid, hydrophilid, and dryopoid beetles (Coleoptera); true flies (Diptera); and caddisflies (Trichoptera).

Aquatic, wetland, and riparian plant species sometime create important habitats within springs. Typical vegetation at larger and minimally disturbed springs in Nevada and Utah includes sedges (*Carex* spp.), rushes (*Juncus* spp.), grasses (e.g., *Distichlis* spp.), and woody phreatophytes [e.g., seepwillows (*Baccharis* spp.), saltbush (*Atriplex* spp.), mesquite (*Prosopis* spp.), acacia (*Senegalia* spp.), willows (*Salix* spp.), cottonwoods (*Populus* spp.), ash (*Fraxinus* spp.), as well as non-native saltcedar (*Tamarix* spp.), palms (*Washingtonia* and *Phoenix* spp.), Russian olive (*Eleagnus angustifolia*), and other species]. Springs vegetation at the lowest elevations (e.g., the lowermost Amargosa River basin) often is limited just to grasses and rushes (USFWS 2017). As with springsnails, springs often can support rare or endemic plant species. For example, endemic wetland plant species at Ash Meadows springs include Amargosa niterwort (*Nitrophila mohavensis*), Ash Meadows lady's tresses (*Spiranthes infernalis*), and spring-loving centaury (*Zeltnera namophilum*); US Fish and Wildlife Service no date). Such species may be restricted to the aquatic margins, or may follow the springbrook channel, which can extend for considerable distances downstream.

The extent of shading of a springs ecosystem by cliffs and canopy overstory strongly influences the extent of wetland vegetation and aquatic macroinvertebrate assemblage development (Ilmonen et al. 2009). Cliff-shaded springs and riparian and higher elevation forested springs typically support lower species richness of aquatic and wetland plant and invertebrate taxa, as well as cooler water temperatures and greater dissolved and particulate organic matter concentration than non-shaded springs. In contrast, springs not shaded by canopies or cliffs have more variable water temperature, greater wetland vegetation development, and higher biodiversity. In addition, although not yet studied in detail, springs vegetation undergoes distinctive successional changes, which likely vary by springs type, regional vegetation, and landscape setting. For example, the establishment of a single Fremont Cottonwood (*Populus fremontii*) at a springs ecosystem can shade, add leaf litter, and attract a different assemblage of fauna, all of which will change when that single tree dies (Stevens et al. *in press*).

Nevada and Utah springs exhibit other biological functions. At landscape scales, aridland springs often are highly interactive landscape patches that strongly influence the ecological integrity and functionality of adjacent upland ecosystems. Energy and material subsidy exchange between springs and the surrounding uplands is multi-dimensional, with species, nutrients, and ecosystem energy passing into and away from springs (e.g., laterally, downstream and upstream, and both into and out from the water column, subsurface environments, and atmosphere; Stevens 2020). The type and extent of energy and material exchange depends on springs type, local geomorphology, and regional to continental location and climate. As such, Perla and Stevens (2008) described aridland springs as keystone ecosystems, small but disproportionally important habitats.

Springs commonly function as ambush sites for predators. Predatory insects, herpetofauna, birds, and mammals concentrate at springs, attacking prey that are attracted to or occupy the springs water, habitat, and other resources (Springer et al. 2015, Ledbetter et al. 2016). Springs also attract human hunters, as revealed by the frequency of human-scarred bones at paleosprings (e.g., Haynes 2008), and the frequency of hunting blinds, spent shotgun rounds, and other evidence of hunting activity found around contemporary springs. Thus, the ambush function of springs extends across the animal kingdom and includes humans. In addition, springs play significant roles as recreational destinations (e.g., hot springs, hiking recreation), as well as important roles in local and regional economics (e.g., Mueller et al. 2017).

Springs also function as climate change refugia for plants, invertebrates, wildlife, and even humans (Nekola 1999, Cuthbert and Ashley 2014). Morrison et al. (2013) experimentally altered flow reduction impacts on a Death Valley springbrook to simulate climate change or flow abstraction effects. They reported significant shifts in water temperature and other aquatic microhabitat conditions. Cartwright et al. (2020) examined the extent to which springs function as refugia under changing climate, concluding that shallow-aquifer springs are likely to provide only limited refugial habitat because they are more likely to become ephemeral or dry out entirely. In contrast, springs fed by deeper aquifers may provide more reliable refugial habitat if those aquifers remain reasonably intact.

Life is disproportionally concentrated and both individuals and species often are tightly concentrated at aridland springs as compared to the adjacent landscapes: commonly more than an order of magnitude of species and individuals occur/unit area at desert springs as compared to the adjacent landscape (e.g., Springer et al. 2015, Ledbetter et al. 2016). Therefore, as ecologically interactive keystone habitats, ambush sites, and refugia for springs-dependent species, aridland springs are biodiversity hotspots that support complex assemblages of aquatic, wetland, riparian, and upland species (Stevens and Meretsky 2008, Stevens 2020).

4. Springsnail Ecology

Overview

Information on springsnail ecology, and the resiliency, redundancy, and representation of springsnail populations have improved through quantitative research on several individual species, providing insight into life histories and the environmental factors affecting their abundance, distribution, and habitat use (e.g., Mlandeka 1992; Mlandeka and Minshall 2001; Sada and Herbst 2006; Sada 2001, 2007; Martinez and Thome 2006; Martinez and Myers 2008; Sada and Rosamond 2013; SNWA 2010, 2011; Sada 2013). While this Strategy includes consideration of 103 springsnail species, the ecology of only a few species has been studied thus far, and most research has not taken place in Nevada or Utah. However, such studies demonstrate that each springsnail species occupies a distinct microhabitat (niche) with distinctive attributes of current velocity, water depth, substrata, temperature, water geochemistry, and interactions with other species. The following discussion summarizes information on springsnail ecology from those studies and illustrates that the complexity of springsnail life histories is comparable to their taxonomic diversity. While additional unique characteristics of springsnail ecology will be revealed as more species are studied, existing data indicate that springsnail stewardship requires detailed knowledge of species life history and habitat requirements.

Habitat Requirements

Springsnails are widely distributed among the springs and low-order stream ecosystems across the Intermountain West, ranging across elevation from below sea level to approximately

2,300 m and in valley floor to low montane settings (Fig. 1; Appendix A). Hershler and Liu (2017) indicate that the more widely distributed taxa are generally more northerly in distribution within the Great Basin, but no conspicuous biogeographic pattern is apparent among these highly isolated endemic species. Despite the wide range of springs discharge, water quality, and habitat conditions tolerated by springsnail species overall, individual taxa are tightly adapted to the water quality of the individual springs in which they occur. The discharge of Great Basin and Mojave Desert springs that support springsnails ranges from << 0.0001 m^3/sec (<<0.004 cfs) to about 0.28 m^3/sec (10 cfs). Individual springsnail species occur in water temperatures ranging from 3°C to 45°C (Appendix A). *Pyrgulopsis* spp. and *Fluminicola* spp. usually occur in colder waters (although several *Pyrgulopsis* spp. occur in warm or thermal springs (e.g., Ash Meadows, Soldiers Meadows, Fly Ranch Geyser, NV; Gila Hot Springs, NM; and Bruneau Hot Springs, ID; Hershler and Sada 1987, Sada and Rosamond 2013, Hershler et al. 2000, Mlandeka and Minshall 2001). In contrast, Great Basin *Tryonia* spp. occur only in geothermal habitats (Hershler et al. 1999; Hershler 2001). Collectively, the springsnail assemblage also occurs across a wide array of geochemical conditions, with electrical conductance varying among springsnail habitats from approximately 100 µmhos/cm to more than 1,550 µmhos/cm (Ledbetter et al 2020; Appendix A).

Although habitat requirements vary widely among native species, individual springsnail species are generally highly habitat-specific, occurring in perennial springs and springbrooks. Few species occupy lakes, ponds, or impoundments, and springsnails do not occur in environments that dry periodically or that are intensively scoured by floods. Therefore, extant populations occur in relatively stable springs that likely have persisted for lengthy periods of geological time (Taylor 1985). Only a few species occupy large rivers (e.g., Archimedes pyrg - *P. archimedis*, Klamath River; Idaho Springsnail - *P. idahoensis*, Snake River) or lakes (e.g., the now extinct Corded Pyrg occurred in Pyramid and Walker lakes; Hershler 1994). Only a few native species occupy natural, lentic (ponded, limnocrenic) spring-fed ecosystems.

Landscape and microhabitat assessments indicate that each species occupies and is narrowly adapted to microhabitats with distinctive physicochemical characteristics. For instance, some species are restricted to cool waters with low specific conductance (low ion concentration), provided by local and mountain aquifers. In contrast, others are limited to geothermal or regional aquifer springs, and some are restricted to waters with specific ranges of geochemistry (e.g., elevated carbon dioxide concentration for Montezuma Well Springsnail (*P. montezumensis*; O'Brien and Blinn 1999). Some species prefer high velocity flow, some slow currents, and some prefer madicolous (shallow sheeting whitewater cascade) habitats (e.g., Hershler 1998; Sada 2007; Sada and Rosamond 2013). Springs with springsnails typically only support a single species. If two or more species co-occur, they are typically, but not always of different genera and have partitioned habitat use in relation to the available physicochemical microhabitats (e.g., Moapa Valley pyrg, Moapa pebblesnail - *P. avernalis*, and grated tryonia - *Tryonia clathrata*) in the Moapa Warm Springs complex; Sada 2007, 2008).

Springsnails are not uniformly distributed within springs or across the array of springs aquatic microhabitats. Sada and Mihevc (2011) and Sada and Herbst (2006) revealed two orders of magnitude decrease in density of both southeast Nevada pyrg (*P. turbatrix*; Fig. 4) and robust tryonia (*Ipnobius robustus*; Fig. 5), respectively, from the source to the springs downstream limit in two Mojave Desert springs. A similar decrease over distance downstream

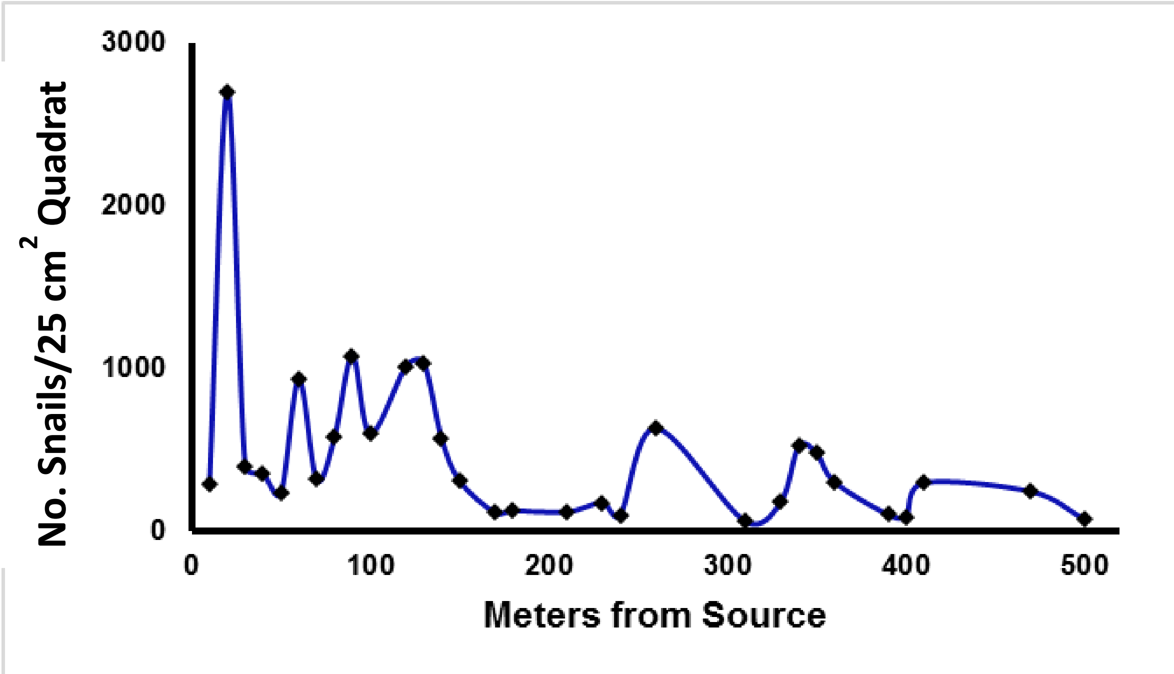

Figure 4: *Pyrgulopsis turbatrix* abundance in 25 cm^2 quadrats along the gradient from the source to terminus in Grapevine Spring, Nye County, Nevada. Data from Sada and Mihevc (2011).

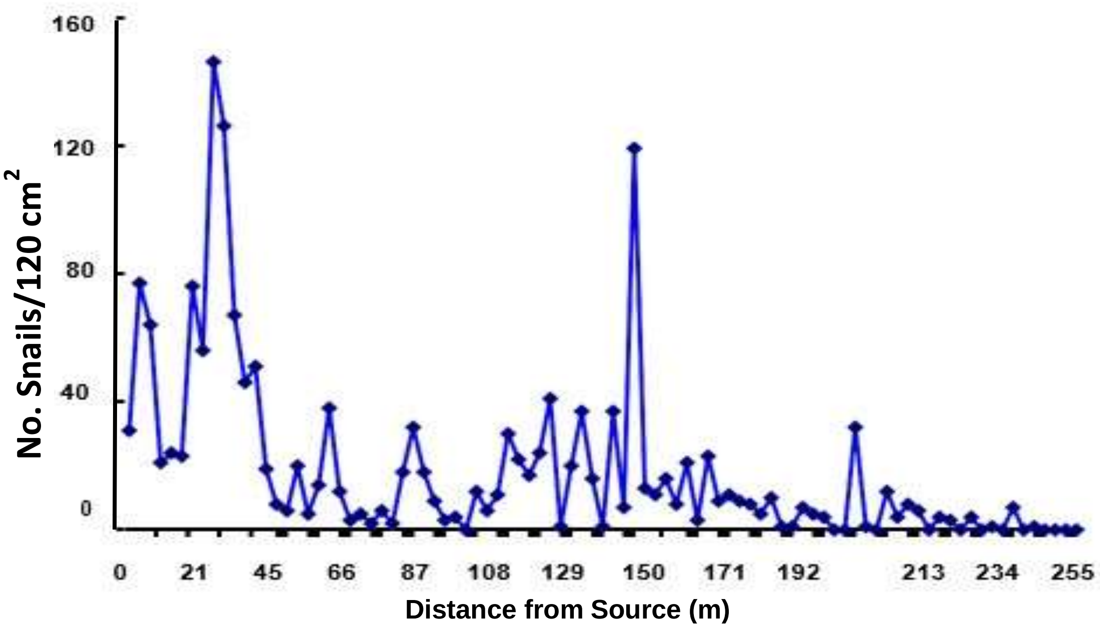

Figure 5: *Ipnobius robustus* abundance in 120 cm^2 quadrats along the gradient from the source to terminus of Travertine Spring No. 1, Inyo County, California. Data were derived from work by Sada and Herbst 2006).

from the source also was observed in Bruneau Hot springsnail by Mlandeka (1992), and in bifid duct pyrg (*P. peculiaris*), longitudinal gland pyrg (*P. anguina*), and Toquerville springsnail *(P. kolobensis*) by Southern Nevada Water Authority (2010, 2011), and in Hualapai springsnail (*P. hualapaiensis;* Hershler et al. 2016b). This pattern of downstream decrease in springsnail density also is characteristic of other springs-dependent (crenobiontic) benthic macroinvertebrates, most likely due to increased temporal variability in pH, dissolved oxygen concentration, and water temperature (e.g., McCabe 1998; Dumnicka et al. 2013).

Springsnails often are associated with site-specific microhabita conditions. Martinez and Myers (2008) reported that Black River springsnail presence was associated with watercress, pebble/gravel substrates, shallow water (~ 8 cm deep), and mean electrical conductivity between approximately 130 µmhos/cm and 135 µmhos/cm. Studies by Sada (2008) in thermal springs of the Muddy River, Nevada (inhabited by three species of springsnails), found that all of these species preferred water temperatures near 32°C. Moapa Valley pyrg preferred shallow habitats (~ 5 cm) with current velocities between 30 cm/sec to 40 cm/sec, and the snails avoided current velocities >50 cm/sec. It also exhibited preference for gravel substrata. Moapa pebblesnail preferred deeper water (~ 30 cm) with swift current (>50 cm/sec) and gravel substrata. Grated tryonia was less abundant than either *Pyrgulopsis* spp. in that system, and preferred shallow habitats (~5 cm deep) with low current velocity (<10 cm/sec). It avoided deeper habitats and current velocities >10 cm/sec, preferring silt and sand substrata, and it avoided gravel and cobble. Also, it preferred habitats with algae and coarse particulate organic matter.

As one of several endemic species In Soldier Meadow, Nevada (Hershler et al. 2007), elongate Mud Meadows pyrg (*P. notidicola*) prefers water temperatures between approximately 34°C and 40°C, water velocities between 5 cm/sec and 15 cm/sec, madicolous habitats that were between 0.1 cm and 1 cm deep, and electcrical conductivity ranging from 400 µmhos/cm to 450 µmhos/cm. Although most springsnails must be submerged, elongate Mud Meadows pyrg occupy a ‘splash zone’ extending to 1 cm above the water on emergent rocks. Its density in the splash zone habitat can be very high, and is correlated with preferred water temperature in their aquatic environment (Sada and Rosamond 2013; Fig. 6). Squat Mud Meadows pyrg (*Pyrgulopsis limaria*) also occupies the same springs, but its interactions with elongate Mud Meadows pyrg are minimal due to its preference for temperatures < 37°C (Sada and Rosamond 2013).

In Death Valley National Park thermal springs, Sada and Herbst (2006) found that robust tryonia preferred warm water (approximately 34°C) and moderate current velocity and water depth. It avoided slow and fast currents (<5 cm/sec and >35 cm/sec), low and high water temperatures (<32°C and > 40°C), shallow and deep water (<4 cm and >14 cm), and open riparian cover (<20% and >80%). Sada and Mihevc (2011) found that southeast Nevada pyrg preferred water temperatures between 17.9°C and 18.7°C, and shallow, (~1 cm) slow moving (~1 cm/sec) water. It did not exhibit a preference for submerged aquatic vegetation, although it was most abundant where watercress occurred; also, it was most abundant where substrates were dominated by fine sediments. It avoided bedrock substrata and spikerush (*Eleocharis* sp.) vegetation.

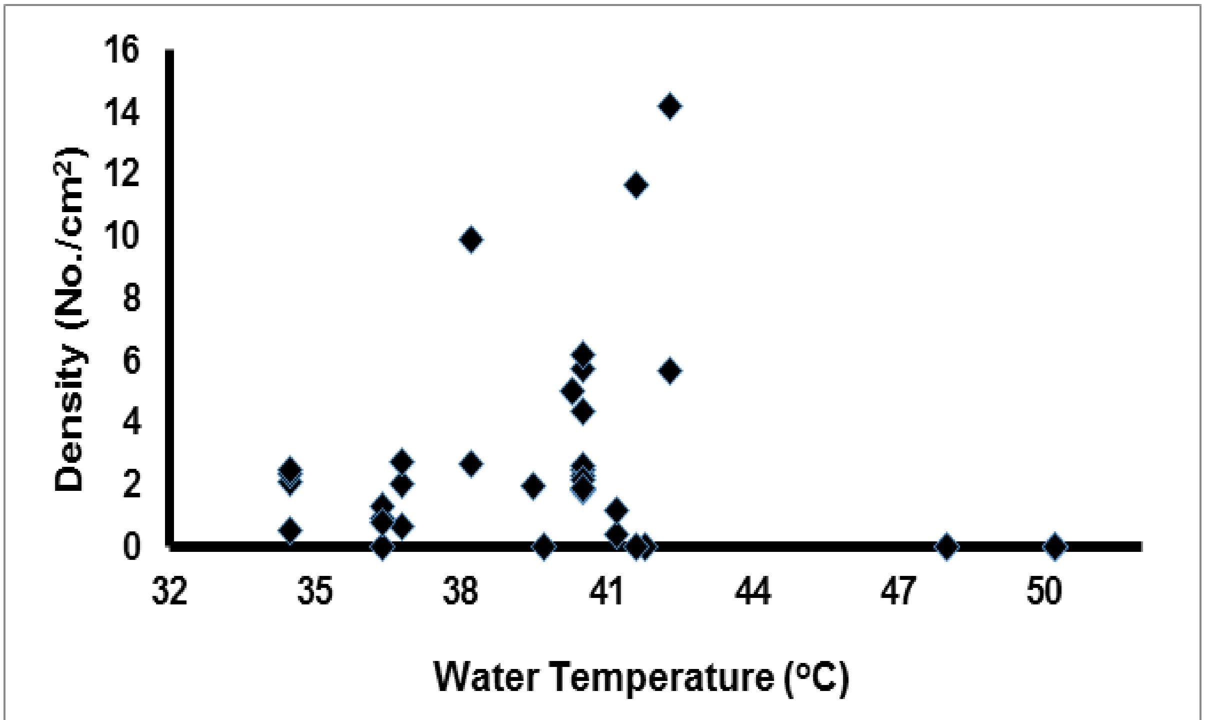

Figure 6: The relationship of *Pyrgulopsis notidicola* density in splash zone habitat on emergent rocks relative to water temperature at Bath and Satellite springs in Soldier Meadows, Nevada (Sada and Rosamond (2013).

Sada (2013b, 2016) reported habitat preferences for longitudinal gland pyrg and Toquerville springsnail by pooling information from studies of four and five springs, respectively. Toquerville springsnail occurred in water temperatures from 12°C to 14°C, current velocities from 10 cm/sec to 20 cm/sec, and water depths from 20 cm to 25 cm. It showed no preference for emergent vegetation in low density, but avoided aquatic vegetation cover exceeding 80 percent. It avoided fine substrata, preferred sand, and it avoided filamentous green algae. Longitudinal gland pyrg was most abundant in water temperatures that ranged from 13°C to 15°C, current velocities from 0.1 cm/sec to 5 cm/sec, and water depths that ranged from 15 cm to 20 cm. It exhibited no distributional pattern in relation to the density of emergent vegetation density until vegetation density exceeded 80 percent. Longitudinal gland pyrg occupied sand as a substratum, but showed no preference for emergent versus submerged vegetation or algae.

Abundance and Population Size

Springsnails often are numerically abundant at springs and in the low-order streams in which they occur in Nevada and Utah; however, determining springsnail population size is challenging due to their small body size, the potential sensitivity of their habitats to sampling, and wide spatial and temporal variability. The abundance of relatively few species has been quantified, but available information provides insight into population size variability (Table 5 and citations therein). In those studies, mean density ranged from 341/m^2 (elongate Mud

Meadows pyrg) to 55,929 /m^2 (San Bernardino springsnail), and density within quadrats within a habitat ranged from near 0/ m^2 for a number of species to 374,000 /m^2 for San Bernardino springsnail. Also, seasonal density patterns are inconsistent: springtime density was highest for some species, while autumn density was highest for others. Mlandeka (1992) found that density was inversely correlated with water temperature in geothermal springs occupied by Bruno Hot springsnail, hence density during the summer heat was lower than during cooler seasons. Elongate Mud Meadows pyrg also occupied geothermal habitats, and its density followed a similar pattern.

The amount of occupied habitat appears to be related to springbrook length, which in the cited studies, ranged from 18 - 520 m^2 (Table 5). Few studies have determined the density of springsnails in occupied areas, so estimates of population size are rare for springsnails. For springs with such data, the amount of occupied habitat ranged from 52.4 m^2 to 1,105 m^2 for Bruno Hot springsnail and robust tryonia, respectively. Estimated within-site population size ranged from 3,000 individuals for elongate Mud Meadows pyrg to 41,387,000 individuals for robust tryonia (Table 5); however, minimum viable population size has not been estimated for these or other springsnail species.

Diet and Feeding

Springsnails feed on algae, diatoms, detritus, and biofilm gleaned from substrata and aquatic vegetation (Furnish and Monthey 2005). Diatoms may be their preferred food, but food ingested by Bruno Hot springsnail was proportional to the availability of algae in its habitat (Mlandeka and Minshall 2001). Enigmatically, and based on observations at numerous springs, many North American *Pyrgulopsis* species appear to be intimately associated with non-native watercress [Brassicaceae: *Rorippa* (*Nasturtium*) *officinale*], seemingly preferring it as a substratum, and occurring on submerged stems and amongst its roots.

Reproduction

Springsnails typically are dioecious (sexual reproduction, with separate male and female individuals), but reproduction rarely may be parthenogenetic (self-fertilization). Furnish and Monthey (2005) studied the life history of six springsnail species among four genera (*Fluminicola, Vorticifex, Juga*, and *Lyogyrus*) in the Pacific Northwest, reporting that these species were generally semelparous, breeding only once in their lifetime and dying thereafter. Female hydrobiids often laid eggs in single capsules on the leaves or stems of aquatic plants and other benthic substrata, but in some species the eggs hatched within the pallial gonoduct and young were birthed alive (ovoviviparous reproduction). Sexual maturity was generally reached by late summer, and >90 percent of the population was likely to reproduce by late summer after several months of growth. Springsnails that survived the winter tended to be adult individuals that had not previously reproduced. Therefore, although data are limited, the longevity of an individual springsnail is likely up to one year in cold to cool-water springs, but shorter in warmer springs.

Table 5. Spatio-temporal variation in density and habitat area of several *Pyrgulopsis* springsnail populations. N = number of quadrats sampled (see individual citations in text), Range = range of density in quadrats, Length = length of occupied springbrook (m), Habitat Area (m^2) = estimated area of occupied habitat, Estimated Population Size = estimated number of springsnails/population. Wetted width of springbrooks occupied by longitudinal gland pyrg (*P. anguina)* and near Toquerville springsnail (*P.* nr *kolobensis*) was not measured (NM), preventing estimation of occupied area and population size (UNK). Data for robust tryonia (*I. robustus)* from Sada and Herbst (2006), elongate Mud Meadows pyrg (*P. notidicola*) from Sada and Rosamond (2013), longitudinal gland pyrg and Toquerville springsnail from SNWA (2010,2011), San Bernardino springsnail (*P. bernardina)* from Malcom et al. (2005), and the summed total of Bruneau Hot springsnail (*P. bruneauensis*) in five Hot Creek springs (Mlandeka 1992). Asterisk denotes geothermal habitat.

Species	Spring Name	Season	Mean Density (number/m^2)	Range of Density/ m^2	Spring-brook Length (m)	Occupied Habitat Area (m^2)	Est'd Population Size
Ipnobius robustus	Travertine Spring 1	Springtime 1998	37,625 (N=32)	0 - 224,910	520	1,105	41,387,000
Ipnobius robustus	Travertine Spring 1	Winter 1999	26,306 (N=8)	7,414 – 53,479	520	275	7,223,000
P. notidicola	Bath Spring	Summer 2012	341 (N=50)	0 – 3,082	100	350	1,200
P. notidicola	Bath Spring *	Springtime 2013	2,757 (N=50)	0 – 31,820	100	251	3,000
P. notidicola	Satellite Spring *	Summer 2012	1,180 (N=30)	0 – 3,852	180	147	16,250
P. notidicola	Satellite Spring *	Springtime 2013	800 (N=30)	0 – 4,330	210	164	13,140
P. anguina	Clay Spring North	Springtime 2010	23,120 (N=100)	0 – 187,200	61	---	UNK
P. anguina	Clay Spring North	Autumn 2010	14,000 (N=97)	0 – 79,200	56	---	UNK
P. nr *kolobensis*	Willow Spring	Springtime 2009	3,960 (N=50)	0 – 19,200	30	---	UNK
P. nr *kolobensis*	Willow Spring	Autumn 2009	5,520 (N=41)	0 – 22,800	25	---	UNK
P. nr *kolobensis*	Willow Spring	Springtime 2010	3,400 (N=44)	0 – 24,800	22	---	UNK
P. nr *kolobensis*	Willow Spring	Autumn 2010	4,080 (N=57)	0 – 58,800	21	---	UNK
P. bernardina	Snail Spring	Autumn 2001	55,929 (N=40)	0-374,000	18	---	UNK
P. bruneauensis (5)	Hot Creek Springs*	Summer 1989	2,089 (N=10)	10-1975	78	52	76,436

Springsnail reproduction may occur throughout the year, but peak periods appear to be in the late winter, spring, and late summer. Mlandeka and Minshall (2001) and Sada (2001) observed several cohorts in monthly and seasonal samples of Bruno Hot springsnail and Badwater snail (*Assiminea infima*) populations, respectively. In the warm water habitats preferred by Bruno Hot springsnail, Mlandeka and Minshall (2001) reported that sexual maturity was reached in approximately two months, and maximum size was reached in four months, and the sex ratio was 1:1.

Ecological Roles

Springsnails can fill important niches in aquatic habitats. These gastropods are primary consumers and detritivores and, when abundant, can play a significant role in energy cycling, linking energy transfer between trophic levels. Specifically, springsnails convert algae, microorganisms, and decaying matter into nutrients that are recycled into springs ecosystem food chains. Springsnails also may influence water chemistry, productivity, and detrital breakdown (Center for Biological Diversity et al. 2009).

Because springsnail species often are extremely sensitive to changes in their habitats, they are considered to be environmental indicator species. Based on their occurrence and population dynamics, they provide evidence of the ecological integrity of their aquatic or terrestrial habitats. The presence of abundant springsnails indicates high ecological integrity quality and persistent aquatic habitat, although not necessarily the potability of water for humans or livestock. Springsnails also provide evidence of long-term resilience of springs and springs assemblages in response to changing climate and hydrology.

Associated Native Species

Nevada and Utah are renowned not only for their diversity of springsnail species, but also for the host of other springs-dependent plants, invertebrates, fish and several other vertebrate species they support. The Nature Conservancy (Abele 2011) listed Nevada springs-dependent taxa of management concern, including: two fungi, one moss, 20 wetland plants, one bivalve, three aquatic Hemiptera, four aquatic Coleoptera, 42 fish, six amphibian, and two mammal species. Species of particular interest include the endemic Amargosa River pupfish (*Cyprinodon nevadensis amargosae*) and rare naucorid waterbugs that co-occur with springsnails in Ash Meadows. In Utah, springsnail habitats also host least chub (*Iotichthys phlegethontis*) and additional invertebrate species.

Population Linkage/Connectivity

Contrary to the general perspective in conservation ecology that habitat connectivity is an important management goal to ensure gene flow and population protection, this may not be the case for springsnails and other springs-dependent species. Nevada and Utah springs often are isolated habitats with relatively short springbrooks that disappear into the ground and thus are not connected to other perennial waterways. Springsnails often are tightly adapted to the spring source and decrease in density downstream from that source. Isolation of their aquatic habitat may protect springsnail populations from non-native aquatic species, such as mollusks (e.g., red-rimmed melania snails, New Zealand mudsnails), red crayfish, American bullfrogs, and exotic aquarium and game fish. Thus, habitat connectivity may be an undesirable attribute for the conservation of springsnails; this should be considered prior to implementation of management actions, and should be evaluated through monitoring.

5. Threat and Stressor Risk Assessment

Overview

Risk assessment is the process of using the best available scientific information to quantitatively evaluate the array and severity of threats and stressors affecting a species or its habitat, and should be comparative among species or springs, or used over time to establish trends. Threats are potential sources of stress that can interfere with springsnail life history and survivability, and thus reduce the viability of a species or its habitat. Such effects can be magnified in the case of imperiled species and can lead to extirpation or extinction. When threats are actualized, they become stressors, detectably degrading or destroying imperiled species habitat(s) and/or reducing population viability. The success of a conservation or recovery program depends on effective risk assessment, which leads to reduction or elimination of stressors, and identifies potential threats to the target species and its habitat.

Threats to springsnails exist across spatial scale in Nevada and Utah, ranging from local (i.e., within the immediate locality of the spring habitat) to non-local scale, specifically due to "far-field" (non-local) threats/impacts (originating beyond the immediate area of the spring habitat). Consideration of the spatial scale of threats and stressors is central in springsnail conservation planning because eliminating a local habitat stressor does not alleviate a stressor operating at the far-field scale. The converse also is true: eliminating a far-field stressor while neglecting local threats may similarly lead to endangerment of the target species. Some threats, such as climate change, are regional in extent, extending across the entirety of the two states.

Springsnails exhibit high levels of endemism in springs throughout the Intermountain West in North America (Hershler 1999; Hershler and Liu 2008, 2017; Hershler et al. 2014a), making their populations susceptible to the impacts of anthropogenic stressors on springs habitats. In some cases, degraded springs ecosystem conditions have reportedly already led to the extirpation or extinction of several springsnail populations and species (e.g., corded pyrg from near Pyramid Lake, Nevada; Fish Lake Valley pyrg from Fish Lake Valley, Nevada; torrid springsnail (*P. torrida*) from western California; mud amnicola from the Utah Lake area). In addition, an unknown number of other springsnail species may have existed in the Nevada and Utah springs ecosystems that once supported now-extinct Great Basin springs-dependent *Empetrichthys* and *Rhinichthys* fish (Miller et al. 1989).

Below we describe five groups of threats and stressors recognized as potentially affecting the representation, resilience, and redundancy of Nevada and Utah springsnail populations: a) habitat degradation, b) over-use for scientific, educational, or personal collections, c) biological factors, d) regulatory mechanisms, and e) other factors. This group of risks factors is used by the USFWS under Section 4(a)(1) of the ESA in listing considerations. However, an additional and pervasive issue in Nevada and Utah affecting springsnail conservation is the inadequacy of basic hydrology, land use, and springsnail population information for risk assessment. High quality information on population status, stressor impacts, and threats are needed to provide collaborative information management planning and implementation. Thus, information collection, sharing, management, archival, and synthesis play essentials role in risk assessment, and is crucial for program success.

Habitat Degradation

Overview

Local and regional threat and stressor risk factors affect Nevada and Utah springsnails. Local risk factors are primarily related to the alteration of springs habitats, which range from local and somewhat more readily managed groundwater and geomorphic impacts, to difficult-to-manage far-field factors related to depletion of aquifers, groundwater and surface water and air pollution, large mining and energy development operations, urbanization, and at a regional scale, climate change. The significance and interactions among local risk factors vary in relation to the level of habitat imperilment within a site, the number of sites at which a species occurs, the array and magnitude of factors influencing those species and sites, and far-field risks related to aquifer depletion and contamination. Local and far-field risk factors are described below and identified in Appendices C-E, which direct SCT activities to meet the Agreement objectives over the next decade.

Local-scale Habitat Risk Factors

Overview: Local scale risks to springsnails and their habitats include water and land use practices at individual springs. Such factors include, but are not restricted to: a) geomorphic alteration of habitat structure, b) flow diversion, c) localized groundwater contamination or depletion, d) livestock and wildlife management and fencing practices, e) recreation impacts, and f) development impacts, as described below.

Geomorphic Alteration—Excavation, berming, draining, or other earth-moving activities are common in Nevada and Utah springs, as is the construction of spring boxes over springs sources. Such developments often can be accomplished while sustaining springsnail populations, and their impacts often are relatively easily remedied, if the supporting aquifer is relatively intact. Burke et al. (2015) describe the remarkable resiliency of Pakoon Springs in northern Arizona to a geomorphic rehabilitation effort.

Flow Diversion—Flow diversion from springs is a common practice that can be compatibly managed for diversion to livestock watering tanks or domestic uses. While the construction of springboxes is mandated to protect potable waters from atmospheric contamination, the practice typically destroys source habitats, which often are required by springsnails. Subsurface flow splitters can divide flow for human use while still allowing emergence at the source.

Local Groundwater Contamination or Depletion—Localized (“on-property” or “nearby”) groundwater pumping can deplete local aquifers. Groundwater quality alteration may arise from excess livestock or wildlife fecal contamination and other agricultural nutrient and fertilizer inputs, local mining activities, as well as inappropriate use of agricultural fertilizer, herbicides, insecticides, application of winter gravel and road deicing chemicals, and unpaved road stabilization compounds.

Livestock and Wildlife Management and Fencing Practices—Many springs in Nevada and Utah are compatibly used for livestock and/or wildlife management. Domestic and feral livestock and wildlife impacts on habitat structure are common at Nevada and Utah springs, and often are similar and difficult to distinguish. Threats posed by livestock and wildlife occupation of springs habitats include trampling and pedestal formation, vegetation disruption and removal, fecal contamination, and surface water quality degradation. Such impacts can largely or entirely eliminate springsnail populations and habitat functionality. However, livestock and wildlife management can be compatible with springsnail conservation: many springsnail populations are resilient and can survive moderate levels of large animal impacts. Appropriate fencing and monitoring can remedy excessive livestock or wildlife impacts on springs sources, where many springsnail and other springs-dependent taxa occur.

Recreation and Development Impacts—Many Nevada and Utah geothermal (warm and hot) springs have been developed for recreational purposes, and relatively few undeveloped geothermal springs remain. Many springsnail species are adapted to warm or even hot springs and can be threatened by recreational hot springs development, including alteration of habitat (e.g., ponding the habitat, construction of concrete tanks and pools, flow diversion, water pollution by chlorination or other contaminants, etc.), as well as by direct recreation use impacts of trampling and repeated disturbance. In addition, many cool to warmwater springs are used for wildlife viewing, as vehicular or backcounty hiking destinations, and are used by hunters to ambush prey. Habitat impacts from such backcountry recreation may involve trampling, off-road vehicle disturbance, trailing, noise, and dust and water pollution.

Far-field Habitat Risk Factors

Overview—Several far-field and regional/continental/global-scale human environmental impacts threaten springsnails and their habitats in Nevada and Utah. These far-field risk factors can affect multiple springs and springsnail species within large portions of the landscape.

Groundwater Overdraft—While drawdown of local water tables is a relatively common phenomenon, large-scale groundwater withdrawal poses a far-field risk to springsnail habitats. Demand for urban, agricultural, and industrial water in the desert Southwest has outstripped available surface water supplies (e.g., US Bureau of Reclamation 2012), and groundwater pumping has greatly accelerated in recent decades, particularly during periods of drought (Stevens et al. 2020). Deep wells can draw down the water table in deep carbonate aquifers, and the intensity of pumping for agriculture, mining, and urban uses can result in lowering the groundwater table and dewatering of the springs that support target springsnail taxa and other springs-dependent species. Groundwater in intermountain valleys can be Pleistocene in age, and recharge rates may be too slow to allow water table recovery before species or ecosystems are eliminated.

Large or Diffuse Mining and Energy Development—Mining and energy development has an illustrious history in Nevada and Utah and provides many jobs in both Nevada and Utah. However, industrial oil, gas, geothermal, and mineral development can alter or fully eliminate springs and springsnail populations. Direct impacts of large mineral mining operations include habitat elimination, spoil storage, surface drainage alteration, water contamination, road construction and use, and fugitive dust generation, as well as legacy effects of early mines. Pumping groundwater from mines can indirectly lower the water table, dewater nearby springs, and permanently alter groundwater flow paths. Hydraulic fracturing can pollute deep and shallow aquifers and cause to wells leak, rendering such water unpotable. Geothermal and renewable energy development also may result in aquifer depletion and loss of springs habitat, as has been documented for Bruneau Hot Springs and its endemic springsnail (Adkins and Bartolino 2012).

Urbanization—The rapid growth of the cities and towns in Nevada and Utah has placed much demand on water supply availability and conveyance. For example, protracted efforts by both Salt Lake City and the City of Las Vegas to secure adequate water for their populations have extended those cities' reach far beyond their city limits (e.g., Lasserre 2016). Groundwater pumping supplies some of the domestic water needed in many cities and towns in this region, and water supplies often are acquired at the expense of the ecological integrity of springs and streams. In addition, springs in close proximity to urban areas can be threatened by recreation and illegal introduction of non-native species (e.g., releasing aquarium fish into a spring). The introduction of non-native aquarium plants, snails, and fish have long been, and continue to be, a major threat to Nevada and Utah springs near urban areas (e.g., Deacon et al. 1964).

Groundwater, Surface Water, and Air Pollution—Due to the proximity of some springs to urban areas and mines, groundwater, surface water, and air quality can be impaired (e.g., Pawlak et al. 2008, Donaldson et al. 2012). The larger cities in these two states (e.g., Las Vegas, Reno, Salt Lake City) generate substantial quantities of dust and air pollution, which can drift into adjacent ecosystems. Light pollution has not been studied in relation to springsnails, but could also pose risks because most springsnail species appear to be negatively phototaxic.

Wildfire—Watershed processes that may be affected by fire include precipitation, interception, infiltration and overland flow, soil water storage, snow accumulation and melt, and surface erosion (Baker 1990). In addition, mineralization of organic matter and loss of shade also can affect water quality by increasing stream temperatures and nutrient concentration (Ice and Neary 2004). Hydrologic responses to fires change proportionately with annual precipitation, with the highest responses observed in areas with annual precipitation over 460 mm (Baker 1990; i.e., higher elevations) and in years with above-normal precipitation (e.g., Brunelle et al. 2010). In contrast, wildfire suppression may promote increased vegetation growth and transpiration, leading to the loss of surface water from small springs. Such issues indicate that evaluation of potential fire impacts on individual springs and springsnail populations should be made on a case-by-case basis, and that at least occasional monitoring is needed to determine wildfire potential and impacts.

Wildfire and prescribed burns strongly affect lowland wetlands and also can affect watershed processes. Wetland wildfire is a common occurrence at the USFWS Ash Meadows National Wildlife Refuge in southern Nevada (Sunderman and Weisburg 2012, Scoppettone 2013). Springs and springsbrooks in Ash Meadows support dense deciduous wetland vegetation, while the surrounding Mojave Desert landscape produces too little fuel to support fire. Sunderman and Weisburg (2012) reported that while fire frequency was high in springbrook wetlands, fire intensity was greatest in adjacent woody stands of mesquite, ash, and tamarisk. However, Ash Meadows springs and springbrooks support at least nine species of springsnails, and frequent low-intensity wildfires apparently have had minimal negative direct impacts on springsnails. While many low elevation Nevada and Utah springs are more isolated and potentially less fire-prone than those at Ash Meadows, invasion by *Bromus*, *Schismus*, and other non-native grasses and herbs can increase fire frequency (Brooks et al. 2004), making desert springs ecosystems more fire-prone.

Climate Change—Climate change poses wide-spread, long-term threats to springsnail habitats. Many climate change models predict increased warming in the southern portions of Nevada and Utah, decreased and more erratic snowpack at upper elevations to the north, and increased unpredictability of extreme climate events, such as drought and severe storms (e.g., US Bureau of Reclamation 2012; Udall and Overpeck 2017). Aquifer recharge in these two states and throughout the arid Southwest varies by elevation, with snowmelt infiltration at upper elevations and surface flow infiltration in low-elevation settings (e.g., Stonestrom and Harrill 2007). Climate change is reducing these sources of infiltration, and demand for groundwater is ever-increasing, adding further threats to springs habitats (Stevens et al. 2020).

Conservation and Management Needs for Addressing Habitat Loss and Degradation

Local Scale—Local, site-specific conservation actions can substantially improve springsnail habitat quality throughout Nevada and Utah if the aquifer is relatively intact (Scoppettone et al. 2005; e.g., Burke et al. 2015; Appendix G). Some stressors operating at local spatial scales, such as flow diversion and geomorphic alteration can be compatibly remedied. However, to manage geomorphic habitat alteration, stewardship actions vary by spring type (*sensu* Springer and Stevens 2009). In general, managing springs for the natural springs type will minimize maintenance costs and generate the most productive and sustainable springsnail habitat (Abele 2011, Springs Stewardship Institute and Sky Island Alliance 2016).

Flow diversion for livestock, domestic, and wildlife uses often exerts localized stress on springs habitats, but those impacts can be compatibly managed. For example, a flow splitter can be installed to allow both the continued emergence of groundwater at the source as well as providing water for human purposes (Gurrieri 2020). The ratio of conserved versus diverted water requires consideration by the steward, but can be balanced by developing off-source water storage tanks, and flow often can be diverted downstream from the source, where springsnail populations tend to occur. However, flow diversion often is plagued by pipe leakage, the maintenance of which is the obligation of the steward. In addition, prevention of local (point-source) contamination is needed to protect water quality.

Readily remedied local impacts on springs and springsnails include the following (Stevens and Meretsky 2008):

1) Livestock and wildlife access to, and prolonged occupation of, springs sources can be compatibly managed by exclosure fencing the biologically important springhead (source),

providing livestock and wildlife water off-site or downstream, with monitoring to ensure the effectiveness of habitat protection over time (Kodrick-Brown and Brown 2007).

2) Hillslope erosion is a common local impact on springs that were or are used as water sources. Construction of a simple steppingstone trail to the springhead allows easier access for the steward and provides hillslope erosion control.
3) Development of hot springs for recreational use can negatively affect springsnails. Although springsnail populations often are highly resilient to minor human disturbances and can tolerate slight geomorphic alteration of their habitats, sufficient monitoring attention to springsnail population integrity and habitat needs is required to ensure their persistence at developed thermal springs.
4) Many, but not all, springsnails require firm substrata near springs sources, habitat elements that can be eliminated by intensive ungulate trampling. Also, many springsnails co-occur with watercress. Depending on the springsnail species habitat requirements, the addition of appropriate substrata (sand, gravel, sticks and logs), and perhaps the addition of watercress, may greatly benefit springsnail and other near-source springs-dependent taxa. Such habitat augmentation may influence other springs-dependent taxa, but should be carefully monitored to assure the persistence of the entire springs assemblage, and to make sure that other non-native vegetation is excluded.

The above local risk factors and potential management actions are identified through a review of available background information, site visits by trained springsnail inventory staff, and conversations with the stewards. This information will be documented and archived in the project database, and used to establish management priorities, which will be reviewed by the responsible agencies and by the SCT. Appropriate management actions will then be planned, implemented, monitored and the SCT collaborators will prepare annual reports to document progress in springsnail conservation. Appropriate remedial actions to reduce these risks will help conserve springsnails and their habitats, and should be designed to minimize project and habitat maintenance costs.

Far-field Scale—The reduction or elimination of broad-scale threats and stressors involves discussion and agreement at a societal level, which are part of the foundation of the Agreement. The SCT needs to be aware of such threats and also what is being done regionally to stay abreast of, or address, potential far-field environmental impacts, such as climate change. However, achieving such discussion will require consistent attention and considerable effort on the part of the SCT, its signatory agencies, and the public in the two states. While difficult to coordinate, such discussions and agreements are essential to alleviate or eliminate risks to springsnails throughout Nevada and Utah.

Hydrological Risk Assessment—Hydrologic risk assessment is important to the conservation of springsnails, as the demand for groundwater in Nevada and Utah is ever-increasing and as climate changes. Hydrological risk assessment often includes consideration of hydrogeology, groundwater pumping scope and intensity, aquifer drawdown responses, and consideration of climate change implications. Groundwater modeling at an appropriate spatial scale can be used to predict groundwater availability, as well as movement rates. Development of local models for individual springsnail habitats may be appropriate for some sites, subject to SCT discussion. Coarse-scale groundwater models are available for some parts of the two states (e.g., Heilwell and Brooks 2011), but their utility at the local scale of springs may be limited.

The SCT's priorities for developing hydrologic risk assessment will be to: 1) acquire and analyze hydrogeological information appropriate to the scale of the springs in question; 2) facilitate model development and testing, where appropriate; and 3) use the analyses and model results to improve prioritization and planning of management actions. The resulting hydrologic risk models to inform stewards about groundwater supplies for target springsnail populations and habitats. In the near term, prioritization of which species and springs warrant management attention can be based on the landscape analysis of urgency metrics, derived from the stressor/conservation measures matrix (Appendices D, E).

An early example of the benefits of groundwater risk assessment and subsequent management on springs-dependent species conservation is the case of Devils Hole. An exposure springs ecosystem located in Ash Meadows in southern Nevada, Devils Hole was declared as a satellite unit of Death Valley National Monument in 1952. Devils Hole was the early focus of desert fish research, but groundwater pumping for irrigation in Ash Meadows (both local and far-field effects) caused water table declines, raising concerns about the continued existence of the then-recently federally listed Devils Hole Pupfish (*Cyprinodon diabolis*; Dudley and Larson 1976). The Department of Justice filed a complaint against the irrigation company, and the Supreme Court halted pumping there in 1976. Eventually, on-going conservation concerns led to the creation of Ash Meadows National Wildlife Refuge in 1984, which now protects Devils Hole, as well as nealy 60 nearby springs, and nearly 30 endemic, springs-dependent plant, invertebrate, and vertebrate species (USFWS 2020).

Land Use Risk Assessment—While local land surface disruptions can be relatively easily detected, understood, measured, and remedied, far-field land use risks are more difficult to identify and resolve. Developing a GIS-based land use risk model at various HUC scales has been conducted by the US Forest Service, and may provide useful information on the condition of lands adjacent to target springs. Fire history, soil and slope variables, vegetation, and critical habitat mapping all may contribute information useful for management planning. The results of such coarse-scale land use risk assessment may be used to score the stressor/conservation measures matrix (Appendix E) and provide prioritization cues for areas proposed for management attention. Also, such models may be useful for monitoring purposes if they are refined and re-run occasionally in relation to a monitoring program.

Over-use for Scientific, Educational, or Personal Collections

Overview

Martinez and Sorenson (2007) detected significant differences in the total size of springsnail populations across their intra-annual sampling periods. Sampling without replacement caused a transitory decline in total population size, although springsnail population abundance recovered again the following year. Springsnail populations also may also be incidentally collected when vegetation or substrate is removed from springs or springbrooks. Such impacts can occur from restoration activities (e.g., removing dense vegetation within a spring), from grazing, or from vegetation removal for personal use (e.g., harvesting watercress).

Conservation and/or Management Strategies to Prevent Over-use

Because springsnails cannot reliably be identified to the species level based on their external morphology, springsnails occasionally are collected to provide voucher specimens or genetic material for species-level verification. Generally, the research or monitoring personnel involved in springsnail studies are well aware of the need to avoid over-collecting individual populations, and should be well-trained in specimen preservation techniques (Appendix B). Such collections should not threaten or deplete any local springsnail population, particularly when relatively few individuals are detected. Both the states of Nevada and Utah require collecting permits to take mollusks. Also, planning and care should be taken to protect springsnails during springs rehabilitation and other management actions.

Biological Factors

Overview

Threats of disease, predation, competition, and hybridization from non-native and sometimes native species generate a wide array of biological challenges to sensitive taxa like springsnails. Many biological risk factors to springsnails, other springs- dependent taxa, and their habitats arise from the introduction of non-native species. A wide variety of non-native species occur at Nevada and Utah springs, including plants, invertebrates, fish, and amphibians. Not all exotic species threaten springsnails, but some non-native species pose severe problems for these gastropods. Non-native invasive species of concern include plants, such as saltcedar (*Tamarix* spp.), several *Bromus* grasses, several herb species, invertebrates (particularly non-native mollusks and crayfish), bullfrogs, and aquarium-released and stocked game fish species. State-based lists of ecologically important non-native species are provided by the US Department of Agriculture at https://www.invasivespeciesinfo.gov/us/.

Disease and Parasitism

Parasitism and disease may affect the springsnails species targeted in this Strategy. However, information on such impacts is limited. Taylor (1987) reported that parasitic trematode infestation resulted in castration in dense populations of springsnails in New Mexico. Non-native red-rimmed melania (*Melanoides tuburculata*) carry at least three parasites of significance to humans, livestock, amphibians, endangered and economically important fish species. These trematodes include *Centrocestus formosanus, Haplorchis pumilio*, and *Philophthalmus gralli* (USFWS 2018). The former species parasitizes all vertebrate taxa (Pinto et al. 2018). The minute intestinal fluke, *Haplorchis pumilio* parasitizes fish, generates anorexia in carnivores and, like *Centrocestus*, can infect humans (Nisson et al. 2013). The trematode eye parasite *Philopthalmus grallii* infests birds and crayfish (West 1962). Nnone of these parasites are known to parasitize springsnails; however, few data are available on parasite infestation among Nevada or Utah species, or the extent to which target springsnail species can harbor or are deleteriously affected by disease or parasitism.

Predation

Overview: Many different types of predators consume small snails that are <4 mm (0.2 in) shell length (Covich 2010). Natural predators of springsnails include waterfowl, shorebirds, amphibians, fishes, crayfish, leeches, and aquatic insects (Martinez and Thome 2006). Larval damselflies (Zygoptera) and dragonflies (Anisoptera) have been observed feeding on snails (Mladenka 1992). Some snail predators, such as some leeches, aquatic insects, and some riparian ground beetles (e.g., *Scaphinotus*) kill snails by either penetrating the shell (Covich 2010), or by eating the snail from the aperture. Some of those predatory species are known to occur in the ranges of springsnails assessed in this Strategy.

Many springs occupied by springsnails are readily accessible to the public, and therefore are vulnerable to the introduction of crayfish and other potential springsnail predators (e.g., Rahel 2004). Blue Point Spring and nearby Rogers Spring in Lake Mead National Recreation Area in Nevada have been sites with much public visitation and occasional release of aquarium fish and other pet trade species (Courtenay and Deacon 1983; Relict Leopard Frog Conservation Team 2016). However, the impacts of these species on springsnails is generally not known. Important non-native species that have extirpated spring-dwelling taxa in the southwestern USA include crayfish (mostly *Procambarus* spp.), mosquitofish (*Gambusia affinis*), mollies (*Poecellia* spp.), goldfish (*Carassius auratus*), cichlid fish, and bullfrogs (*Lithobates catesbeiana*; Sada 2016). Johnson et al. (2013) identified several families of fish known to prey on springsnails in the USA and Canada, including the families Acipenseridae, Cyprinidae, Catostomidae, Ictaluridae, Centrarchidae, and Percidae. Field experiments in Cuatro Cienegas, Mexico, demonstrated that hydrobiid snails (such as *Mexipyrgus churinceaus*) increase threefold in density when predatory fishes were excluded (Covich 2010).

Remnants of Page springsnail shells have been reported in stomach content analyses of mosquitofish from the Oak Creek Springs complex in Arizona (Raisanen 1991). Within Nevada, Sada (2016) observed mosquitofish presence but not predation in Muddy River, Moapa Valley, and Pahranagat Valley springs. Additionally, non-native fish co-occur with the Moapa pebblesnail, Moapa Valley pyrg, grated tryonia, Blue Point pyrg, Pahranagat pebblesnail, Hubb's pyrg, sub-globose Snake pyrt, White River Valley pyrg, bifid duct pyrg, and many others. Although fish predation is possible in their habitats, none has been documented to date. Additional research is needed to determine if there are any population-level effects of non-native fish on springsnail species.

Non-native Crayfish: Aquatic ecosystems can be deleteriously affected by introduced, predatory crayfish (Hershler 1998, Sada and Vinyard 2002, Twardochleb et al. 2013). Kilburn (2013) found that springs in Ash Meadows, Nevada containing non-native crayfish consistently had fewer other faunal species and contained little to no endemic springsnails. Animal material was present in 93 percent of crayfish guts analyzed, with one gut filled entirely with native springsnails and riffle beetle (Elmidae) larvae. Such levels of predation can reduce or eliminate springsnail populations.

Invasive crayfish species influence springsnail populations through direct consumption and also by alteration of springs habitat by altering water quality, sediment characteristics, native fauna, and vegetation composition. Crayfish can quickly become dominant predators in newly invaded aquatic ecosystems, and can initiate novel trophic cascades, altering ecosystem structure. The potential negative effects of non-native crayfish include: competition for food and space; transfer of disease; consumption of eggs with resulting reduction of snail populations; consumption of macrophytic vegetation with indirect and direct effects on other invertebrates; clouding the water with suspended solids due to digging and swimming activity (reducing photosynthesis); and destabilizing ditches, canals, and stream banks (Utah Division of Wildlife Resources 2015). Five species of invasive crayfish have or may eventually have negative impacts on springsnail populations in Nevada and/or Utah.

Red Swamp Crayfish (Procambarus clarkii): Native to the Gulf coastal plain and southern Mississippi River drainage, this species has been recorded in Lake Mead, springs in Clark, Nye, and Elko counties in Nevada, and in Tooele County in Utah. This crayfish species is popular in the aquarium trade where it is advertised as freshwater "lobster" and in the biological supply trade where it may be released following laboratory or classroom use (Larson and Olden 2008). It is also popular among anglers as bait for largemouth bass, and commercial culture for human consumption in the southern USA is an important industry (USFWS 2015a, Global Invasive Species Database 2020b).

Adult red swamp crayfish range in length from 55 to 120 mm and exhibit considerable ecological plasticity. It is tolerant of pH values from 5.8-10, oxygen levels >3 ppm, and water temperatures from just above freezing to 35°C (Huner and Barr 1991). Red Swamp Crayfish diet consists of both plants and animals such as mollusks and snails, insects, fish, and other crayfish. Juveniles consume more animals than adults. These crayfish can live two to five years and reach sexual maturity in as few as two months. In addition, breeding male crayfish are highly mobile, traveling as far as 17 km from their site of origin within four days (Global Invasive Species Database 2011). This species may be parthenogenic.

Virile Crayfish (Orconectes virilis): This species is native to Missouri, upper Mississippi, lower Ohio and the Great Lakes drainages. It is now present in the Lower Virgin River in Nevada and in many locations in Utah. Virile crayfish is popular as live bait among anglers. It is also popularly consumed as food in the USA. Virile Crayfish were stocked primarily for vegetation control in the Colorado River watershed of western New Mexico and northeastern Arizona beginning in approximately 1950 (USFWS 2015e, Global Invasive Species Database 2020a).

Virile crayfish adults range in length from 46 to 125 mm. The species occurs in streams with moderate flow and turbidity, abundant cover, and stable water levels, and it prefers rock or cobble substrata. Virile Crayfish feed on macroinvertebrates such as snails and insects, small fish, fish eggs, tadpoles, and macrophytes, and scavenge dead animals (Hamr 1998, Global Invasive Species Database 2020a). The maximum lifespan is three years. Virile crayfish also is known to cause the decline of native snails, as in the case of Black River springsnail in Arizona (Davidson et al. 2010).

Rusty Crayfish (Orconectes rusticus): This species is native to the Ohio River basin, and is present at Spring Mountain Ranch State Park in Clark County, Nevada. Nevada and Utah both placed this species on their Watch Lists. This species is likely spread by anglers dumping live bait buckets (USFWS 2015b). Rusty Crayfish are large and reach sexual maturity after about one year (Lodge et al. 1985). Lodge and Lorman (1987) reported that snails are among its preferred food, and that its aggressive nature, rapid population expansion rates, dense populations, and its ability to spread through bait trade make rusty crayfish a highly problematic aquatic invasive species.

Signal Crayfish (Pacifastacus leniusculus): Native to the northwestern USA and British Columbia, this species is present in Lake Tahoe, Lahontan Reservoir, and water bodies in western Nevada, and in Utah County, Utah where it may have been introduced (Johnson 1986). These large crayfish can reach 160 mm in length or more. Signal crayfish will occupy a wide range of habitats including small streams, large rivers, natural lakes, and culture ponds. These crayfish may live up to 10-20 years. Once introduced into a new ecosystem, this crayfish alters habitat and reduces abundances of macroinvertebrates and macrophytes (USFWS 2015d).

Australian Red Claw (Cherax quadricarinatus): Native to Australia but intensively farmed as "freshwater lobsters", this species currently is on state watch lists across the USA. This species already has become established in Puerto Rico. These crayfish thrive in temperatures between 15-30° C, and have been grown successfully in USA research ponds over the last several years. These very large crayfish may reach a total length of about 250 mm and weigh up to 0.6 kg. Although popular in the aquarium trade, this species is presently restricted to tropical and subtropical climates, and to water temperatures that do not fall below 10-14°C. Its preferred climate range most closely matches that of Florida and Texas in the USA (USFWS 2012a), but this species likely would do well in the warm springs of Nevada and Utah, and hence is included as a potential threat to springs in the two states.

Non-native Fish: Non-native aquarium and game fish in the American Southwest threaten native fish populations through competition and predation (e.g., Deacon et al. 1964, Meffe 1985, Moyle 1986). However, non-native fish predation impacts on native aquatic invertebrates in the Nevada and Utah have not received much scientific attention. Non-native mosquitofish have been widely introduced throughout the Southwest for mosquito control. However, this small species does not reduce mosquito populations and it has large impacts othe ecology of southwestern springs and other aquatic ecosystems (Courtenay and Meffe 1989). They prey on zooplankton and other small aquatic invertebrates, often reducing invertebrate populations and out-competing native fish species. The introduction of South American suckermouth armored catfish (Loricaridae: *Pterygoplichthys anisitsi*) into Gandy Warm Springs in Utah presents an urgent threat not only to the endemic *Pyrgulopsis saxatalis*, but also to speckled dace and other springs-dependent fauna there.

Non-native game fish species also pose considerable threats to Nevada and Utah springsnails and springs habitats (e.g., Scoppettone et al. 2005, Sigler and Sigler 2014, Wheeler 2019c). Non-native species that have been widely introduced and are of concern include: smallmouth bass (*Micropterus dolomieu*), *Lepomis* sunfish, perch (*Perca* spp.), and other Centrarchidae; threadfin shad (*Dorosoma petenense*); cyprinid bait species; sailfin molly (*Poecilia latipinna*) and other aquarium fish; mosquitofish, common carp (*Cyprinus carpio*); various catfish species (Ictaluridae, Loricariidae); and *Tilapia* cichlids. Many of these non-native fish are potential springsnail predators, and they also consume other springs-dependent organisms, and some also feed on vegetation. However, dietary studies of these various and potentially important predators in Nevada and Utah springs have rarely been examined, and more research is warranted.

Spring pool and springbrook channel habitat rehabilitation can enhance native over non-native fish assemblages, reducing impacts on springsnails. Rehabilitation of natural springbrook habitat at King Spring, Ash Meadows National Wildlife Refuge resulted in proportional increases of Amargosa pupfish (*Cyprinodon nevadensis*) and Ash Meadows speckled dace (*Rhinichthys osculus nevadensis*) populations over non-native sailfin molly, mosquitofish, and sunfish (Scoppettone et al. 2005). These results indicate that springs habitat restoration can be beneficial in creating habitat that is more suitable for native species than non-native species. However, more research on springsnail habitat restoration is warranted.

***Other Invasive Predators*:** Bullfrogs are known to predate upon a wide array of aquatic and wetland fauna, and have been widely introduced into southwestern springs. Native and non-native toads, frogs, and occasionally introduced western tiger salamander (*Ambystoma mauvortium*) are known to co- occur with southwestern springsnails (e.g., grated tryonia, Pahranagat pebblesnail, White River Valley pyrg, Spring Mountains pyrg, and Lake Valley pyrg). While amphibians have been identified as potential predators of springsnails, no data yet point to a strongly detrimental role of amphibians on springsnail populations.

Competition

Overview: Invasive and non-native species, and to a lesser degree native species, are known or presumed competitors of springsnails, competing for food and living space. These species can indirectly affect springsnails by changing ecosystem structure and function (Brown et al. 2008; Lysne et al. 2008; Sada 2016). Ecosystem changes include disruption of the algal food base, nutrient recycling, and fluxes in bacterial production, as described by Mehler and Acharya (2014) at Rogers Spring (near Blue Point Spring; Courtenay and Deacon 1983). Invasive and non-native competitors also can change the dominance relationships among gastropods and result in losses of native species (Covich 2010). Population- and rangewide-level effects typically occur only when high numbers or dense populations of invasive species exist in springs. Reduction of springsnail species through competition has yet to be documented; however, competition is regarded as a threat to springsnail population integrity.

Native Competitors: Brown et al. (2008) found that springsnails that co-occur in large spring systems with greater habitat heterogeneity appear to co-exist with competitors through spatial habitat segregation. For example, Sada (2008) described an assemblage consisting of native Moapa pebblesnail and Moapa Valley pyrg springsnails co-occurring with non-native red-rimmed melania (*Melanoides tuberculata*) in southern Nevada. Both native springsnail species occupied a wide diversity of habitats, but each species also exhibited discrete preferences for a range of depths, velocities, temperatures, and substrata. Nonetheless, some habitat niche overlap occurred among the three species, suggesting that competitive interactions minimally influenced the population structure and distribution of native Moapa pebblesnail and Moapa Valley pyrg, However, the extent to which competitive impacts exist between red-rimmed melania and other native springsnail species remains to be studied.

Non-native Competitors - Overview: Invasive snails affect native snails directly through competition for food and space or indirectly through changes in ecosystem function or parasite populations (Brown et al. 2008). Some of these invasive snails include the red-rimmed melania and New Zealand mudsnail (*Potamopyrgus antipodarum),* which recently colonized water bodies throughout the West (Hershler et al. 2014a, Benson et al. 2020), including the Crystal Springs cluster in southern Nevada, where Hubb's pyrg and grated tryonia both occur, and Blue Point Spring where Blue Point pyrg occurs in Lake Mead National Recreation Area. Both invasive snail species primarily reproduce asexually and frequently achieve high densities at localities where they co-occur with springsnails. The array of impacts among the presently known non-native species that threaten springsnail populations and habitats are described below.

Red-Rimmed Melania (RRM; Melanoides tuberculata): This invasive aquatic snail is rapidly expanding its range across the USA. Native to northern Africa and southern Asia, this tropical freshwater snail was first introduced to the USA in California prior to 1937. They are now widespread across Nevada and Utah, among other states. Adult snails are generally 20-40 mm although they can grow larger in some climates. Snails can live for two or more years. Coloration is usually light brown with mottled rust colored spots, and they have an elongated conical shell. The USFWS rates RMM History of Invasiveness: High, Climate Match: High, Certainty of Assessment: High, and Overall Risk Assessment Category: High. Parthenogenesis allows even the introduction of a single individual to result in development of large populations (USFWS 2018).

RRM are tropical, and the species appears to be restricted to standing or slow-flowing waters between 18°C and 31°C (Rader et al. 2003). Prolonged time periods outside of this thermal range may prove lethal to the snails. This species burrows into the substrate during daylight hours, making detection of live individuals more difficult (L. Stevens, Springs Stewardship Institute, personal observation). RRM has a moderate tolerance to desiccation, but mortality rapidly increases after 18 days at 26°C in a dry enamel pan, with all snails dead after 25 days of exposure (Dudgeon, 1982). Decontamination of recreational and scientific equipment between spring locations is necessary to slow or prevent the spread of this species.

RRM are reported to competitively displace native gastropods, elevating concern for endemic populations of southwestern springsnails (e.g., New Mexico Aquatic Invasive Species Advisory Council 2008). In a five- to eight-year period after introduction of RRM into a Bonneville Basin springs complex in Utah, the non-native snail was among the most abundant species in terms of biomass and number (Rader et al. 2003). RRM also are abundant in some southern Nevada springs, such as those in Ash Meadows and Lake Mead National Recreation Area. RRM invasion may not immediately exert strong negative impacts on native springsnails, such as the Blue Point pyrg because of high habitat heterogeneity, allowing native species to partition habitat use and thereby coexist with the invasive species (Sada 2016); however, such relationships can change, warranting continued monitoring.

New Zealand Mudsnail: Non-native New Zealand mudsnail (NZMS; *Potamopyrgus antipodarum*) is an invasive hydrobiid, rapidly expanding its range across the USA, and reaching remarkably high densities in the generally lotic aquatic habitats it has invaded (Schreiber et al. 2003, Hall et al. 2006, Benson et al. 2020). Native to New Zealand and surrounding islands, NZMS feed on periphyton, diatoms, and organic debris. They tolerate waters from 0-28°C, salinities up to 12 ppt, and depths from 0.05-45 m. They prefer constant, stenothermic habitats with high primary productivity, habitat characteristic of many of the region's springs (e.g., Richards et al. 2001, Kolosovich et al. 2012). They are live-bearing, and often reproduce by selfing (parthenogenesis), which allows a single female to produce more than three million offspring/yr. They have a dextral (right-handed) coiling shell and grow to 6 mm in length. Their color ranges from light brown to grey and dark brown (USFWS 2015a, Benson et al. 2020).

NZMS were first discovered in the USA in Idaho in 1987, with the first Utah population reported in 2001 (Vinson 2004, USFWS 2015c), and invasion of Lake Mead by 2010. In high densities they may threaten native springsnails and other benthic springs taxa through competitive exclusion; however, invasion impacts on native species remain uncertain (e.g., Schreiber et al. 2002). NZMS threats to North American aquatic ecosystems and endemic springsnails are exacerbated by its small body size, ability to withstand desiccation and temperature variation, as well as parthenogenic reproduction. This species now occurs in high densities ($>10^4/m^2$) in many freshwater aquatic settings (USFWS 2015c).

Several studies of non-native NZMS and native Jackson Lake springsnail interactions in the western USA revealed asymmetric interactions between the two species. The invasive species limited the growth of the native snail, and the native snail facilitated growth of the invasive snail by improving foraging conditions (Riley et al. 2008). They reported a significant reduction in the growth rate of native Jackson Lake springsnail (*Pyrgulopsis robusta*) in the presence of NZMS in the Snake River drainage. NZMS impacts have also been documented on native macroinvertebrates, mollusks, and fish.

Spread of this species occurs through agriculture (live fish or fish egg transport), aquarium releases, thr as distribution on boat hulls, or by consumption and/or excretion by birds and fish, inadvertent human transport by anglers, swimmers, and transport on animals (USFWS 2015c). The USFWS rates NZMS Invasiveness as high, Climate Match as high, Certainty of Assessment as high, and Overall Risk Assessment category as high. However, reliable mapping and monitoring, and additional laboratory and *in situ* field studies are needed to understand on-going and potential impacts of NZMS on Nevada and Utah springsnails and other springs- dependent taxa.

Hybridization

Hybridization among springsnail populations, and the overall genetic integrity of Nevada and Utah species does not presently appear to be a significant conservation concern. Springsnail biodiversity has arisen through periodic isolation under changing climates over evolutionary time, and thus reproductive barriers between species already appear to be robust. However, hybridization and genetic contamination may possibly arise if population reintroductions or translocations are undertaken into habitats already containing springsnail taxa. Consequently, hybridization threats should be thoroughly reviewed by the state wildlife management agencies and the SCT prior to any population translocation efforts.

Conservation and/or Management Needs for Biological Stressors

The success of remedial actions through the removal of biological stressors and threats will vary in relation to the species and the sites involved. Springsnails have been remarkably resilient to Pleistocene-Holocene climate changes, but now be may be risk due to the collective impacts of intensive, continual livestock presence, non-native species impacts on populations and habitats, as well as the physical impacts of groundwater depletion and pollution, and geomorphic habitat alteration. Best management approaches require understanding the extent to which such impacts can be prevented through appropriate timing, as well as effective education and outreach. For example, the Utah Department of Natural Resources initiated the highly effective “Don’t Ditch a Fish” public awareness program to combat the problem of translocation of game and aquarium fish into springs and other natural waters. Direct control measures for crayfish and other non-native species are costly and time-consuming, but may be required in some cases. The impacts of rotenone, a chemical used for managing fish populations, are not known for springsnails but warrant study.

Adequacy of Regulatory Mechanisms

Springsnail management approaches are currently evolving in Nevada and Utah. Both states permit and place restrictions on collection, harvest, or disruption of springsnail populations on federal and state lands, but deleterious habitat alteration is only now beginning to be recognized as a threat to these taxa. Present agency policies and statutes listed in the Agreement appear sufficient to protect, enhance, and remediate impairment to springsnails and their habitats on state and federal lands. However, periodic review by NDOW and UDWR of the results of such scientific activities may reveal geographic and population trends, as well as the disposition of specimens and the results of non-governmental research projects. The adequacy of regulatory protections will continue to be reviewed by the SCT.

Other Factors

Climate Change

Among the most challenging issues facing aquatic species conservation are the complex and far-field potential impacts of climate change (US Bureau of Reclmation 2012, Gaufin et al. 2013). Climate change adaptation strategies have been developed by many agencies and organizations; however, springs have only recently attracted public, scientific, or policy-based attention. Cartwright et al. (2020) presented a risk assessment model for springs as climate change refugia, but noted that groundwater depletion was likely to accompany climate change, reducing the ability of springs to support aquatic species. Upper elevation mountain block aquifers that depend on snowmelt are more likely to respond to available precipitation and support springs with “youger” waters, albeit with greater dynamism than low-elevation valley floor aquifers, which rely on surface flow infiltration from geologically structural (fault- or fracture-controlled) channels or groundwater with longer residence times. In addition, wildfire frequency is likely to increase as a consequence of warmer, drier conditions, increasing infiltration in burned forest landscapes, counteracting climate-change-driven increases in evapotranspiration (e.g., Schenk et al. 2020). Morrison et al. (2013) reported systemic impacts of experimentally reduced springs discharge on the physical characteristics of a Death Valley springbrook, and discussed potential impacts on springs-dependent species. Among the impacts reported were increased stream water temperature, reduced habitat area, and altered geochemistry. In addition, adjustment of habitat use and increased keystone ecosystem functionality may involve greater concentration of species at springs and increasing importance of springs to adjacent uplands. Resolving uncertainties about climate change impacts on infiltration processes and springs discharge will require improved monitoring data and analyses.

Information Gaps

Accomplishing the overall goal of this Strategy requires a well-organized suite of inventory, research, and assessment tasks, as described in the Conservation Plan (Section 6, below). Past studies have focused on taxonomy, but relatively little on springsnail ecology, life history, or the options and effectiveness of various population and conservation practices. Hydrologic and ecological modeling may improve prediction at local scales, and climate change impacts on springs and associated species at far-field scales. Thus, a prioritized research agenda is needed to help the SCT improve springsnail management and monitoring over time.

Integrated Information Management

A key need in a bi-state, multi-agency conservation program of this magnitude is an information management system that is well-integrated, easy-to-use, secure, online, and collaboratively sharable. Integrated information management on springsnail taxonomy, distribution, inventory, population and habitat status, assessment, research, planning decisions, implementation, monitoring, and report production and archiving are essential to the success of this multi-species conservation program. Collaborators will need to be familiar and comfortable with that information management system, as well as data entry and retrieval, quality control, and reporting from it. Thus, both a well-maintained information management program and a well-trained corps of collaborating users are essential for program success.

Public Education and Awareness

Although springsnails are exquisite and delicate organisms, they are likely too diminutive to excite significant public attention. The public is generally aware of the importance of water in these arid regions, but the values that private landowners place on their springs are poorly known. Such information is crucial to understanding springsnail habitat protection options. Conservation emphasis on the sustainability of springs may attract broader public support. The SCT will rigorously pursue education and outreach to expand public appreciation of springs and the springsnail species they support through Objective 5 (below), thereby encouraging balanced, sustainable management and public awareness about these fragile, important habitats and the species they support.

Conservation and Management Needs for Other Factors

Climate change and widespread public mistrust of governance are daunting obstacles facing the conservation of springsnails in Nevada and Utah. Renewed effort to better understand climate change patterns and consequences requires an adaptive approach that considers valuation of native species and natural ecosystems. Achieving the objectives of the Strategy will require continuing commitment on the part of the signatory agencies to support adaptive management, natural resource valuation, public education, and outreach, as well as the use of socially equitable management practices. Not only will this program be highly informative about springs and springsnail conservation, but it also will illuminate the broader issues of sustainable water resource management for the future of Nevada and Utah.

6. Conservation Program

Introduction

The purpose of this springsnail conservation program is to provide guidance for coordinated, long-term conservation of species and their habitats in Nevada and Utah through the Strategy's five objectives (Table 1). Adaptive management and risk assessment are two tools in this program to ensure appropriate, timely, and effective collaborative conservation actions. Information management and outreach efforts are critical to documentation, data archival, reporting, and continued learning over the next decade of the program, and a well-developed outreach component is essential to garner public support for conservation efforts by the SCT. Due to the limited extent of available information and the need for adaptive management, this Strategy document is regarded as a living document, to be at least annually reviewed, updated, and refined by the SCT.

The overall goal of the Agreement is to conserve at least 103 springsnail species that are distributed among several thousand springs in Nevada and Utah. The Strategy will do so by:

a) maintaining a clear, well-supported organizational structure;
b) coordinating communications, assessment, priorities, and actions among SCT collaborators;
c) encouraging planning based on coordinated, high quality science;
d) conducting risk assessment using the best available information;
e) establishing a habitat and population management and monitoring program that are effective, efficient, and long-term in scope;
f) sharing information collaboratively through a well-maintained, reliable, secure, easy-to-use, online, relational database;
g) adhering to local, state, and federal regulations and guidelines;
h) retaining the flexibility required for effective adaptive management;
i) providing clear outreach and eduction to the public, Native American tribes, NGOs, and state and federal agencies.

As a living document, the Strategy is expected to be refined over the course of the program. It is hierarchical in relation to the terms of the Agreement, recognizing the need for high quality information management, and coordinated assessment, implementation, monitoring and feedback to improve program effectiveness and efficiency through adaptive management (Fig. 7). Annual reporting of program progress provides the administrative feedback to the signatory agencies. A successful springsnail conservation Strategy will meet the Agreement goals and objectives through and beyond the life of the program. How each objective will be achieved is described below.

Objective 1: Information Acquisition and Management

Preliminary elements of this objective were accomplished by the SCT in 2019; namely, development of a comprehensive species list (strategy 1) has been compiled based on the best available data. The database is organized to receive annual inventory and monitoring information from collaborating agencies and researchers, and periodically provides automated reporting available data. That information is made available to all SCT collaborators through

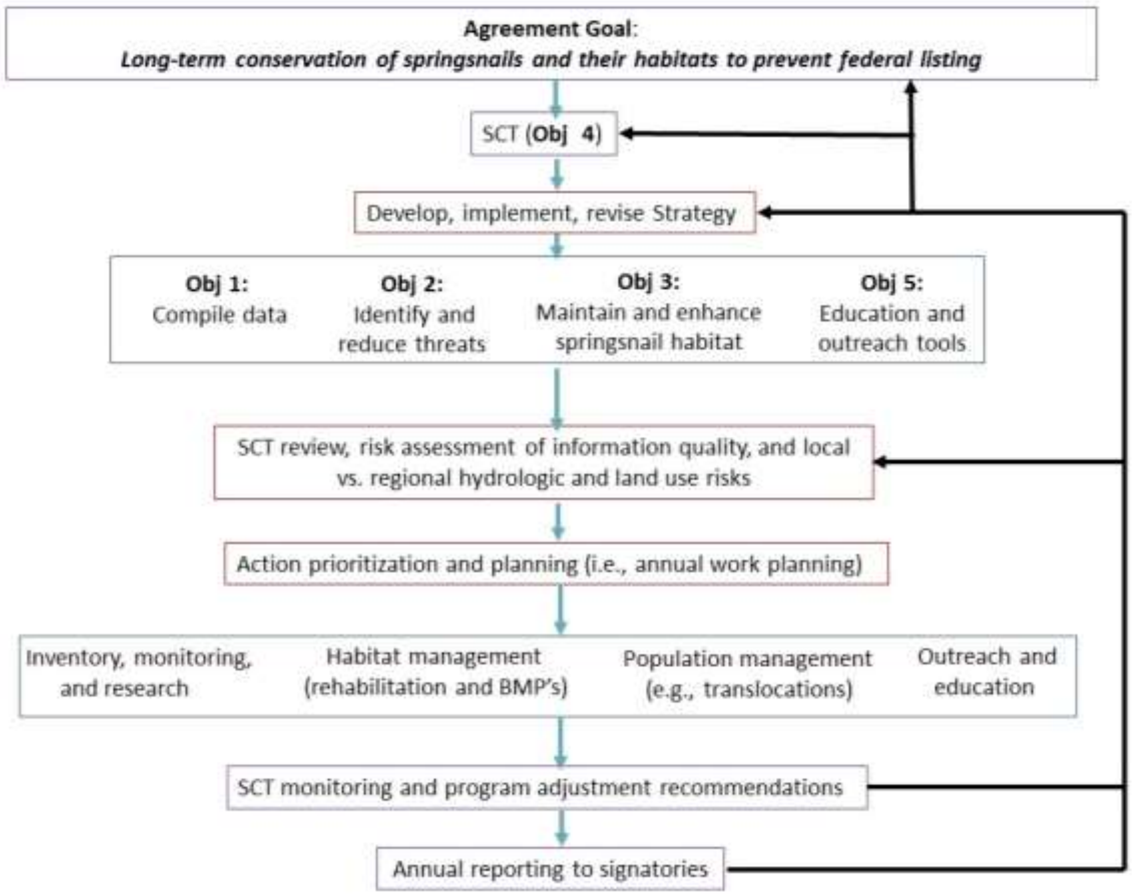

Fig. 7: Diagrammatic representation of the springsnail conservation organizational plan, based on an adaptive management approach, to achieve Agreement goals.

Springs Online. Summaries on the conservation status of each population and its habitat status can be updated automatically (Appendix A). Through this information strategy, the opportunity exists to improve working relationships with other agencies and landowners about springsnails. As it is populated, the database provides an increasingly robust means of assessing population distribution, status and, where information is available, trends through time. Such information can help identify sentinel sites and indicator species, and can serve in assessment of far-field impacts on springsnails, including urbanization, development, and climate changes. This information also provides for prioritization based on information quality. Nonetheless, many uncertainties remain about the target species, their habitats, and threats. Only about 12 percent of Nevada and Utah springs have been inventoried (Sada and Lutz 2016, Ledbetter et al. 2020), and some species have not been recently detected. This first Objective also calls for convening a state of knowledge symposium on springsnails and their habitats to present and review the program structure, approach, existing data, protocols, and implementation and outreach plans, and to seek advisement from experts and the larger scientific community. This state of knowledge symposium may be convened electronically, and should set the stage for advancing Strategy objectives, and the results will be archived on the Springs Stewardship Institute website.

The second strategy under Objective 1 involves review of the available information, refinement of inventory and monitoring protocols, the conduct of prioritized, standardized field inventories to fill data gaps, updating taxonomy, providing collaborative information sharing, and the maintenance and improvement of the database. Recommended springsnail inventory and monitoring protocols are provided in Appendix B (Sada 2019). While similar protocols many be used to ensure data continuity by agency programs that are already on-going, as long as the core information provided through the Sada (2019) protocols are gathered, those protocols can be entered into the Springs Online database (e.g., Wheeler 2019a-c). Springs Online is designed to facilitate data acquisition and sharing, as new information is gathered, including taxonomic changes, and is readily modified as needed. The data entered into Springs Online are used to periodically generate an automated update of each target species. Specific approaches will likely be needed for individual conservation efforts.

Accomplishing the first objective also involves development of an easily accessed, searchable master bibliography of Nevada and Utah springsnail literature. The SCT created a master bibliography that presently contains >450 references (Appendix F) in Microsoft Excel format that is fully searchable. Selected references can readily be downloaded, and it is stored on Springs Online. References can be linked to individual springsnails species, to individual springs, or regions of the study area (e.g., individual HUCs or counties). The bibliography also is designed as a living document, and can store additional references as they are discovered or become available.

Additionally, this first objective requires a research agenda that includes, but is not limited to an array of basic and applied research elements (Table 6). The list of research topics will be annually re-evaluated and prioritized by the SCT. It also falls to the SCT collaborators to support and implement further inventory data acquisition, and advanced taxonomic, ecohydrological, and socio-economic research to fill information gaps and program needs.

The success of the Strategy depends on active collaboration by the signatory agencies. Annual or more frequent SCT meetings are needed to prioritize and facilitate information acquisition, data entry, and conservation planning and implementation. Training of land and natural resource managing agency staff is needed to ensure consistent and reliable conduct and coordination of springsnail inventories, as well as data compilation, entry, archival, and sharing through the Springs Online database. Thus, the signatory agencies will need to consider annual funding support for, and participation in the SCT, as well as database maintenance and engagement of their constituency in the effort, and prompt implementation of SCT recommendations into annual operating plans. Thus, continuing commitment to the program is essential to achieve the goals and objectives of the Agreement and Strategy.

Objective 2 – Identify, Assess, and Reduce Threats

Overview

Identification, assessment, and reduction of stressors and threats require agreement about those terms and the recognition that agency missions differ. It is important that the SCT cooperating agencies share a common lexicon regarding those terms. However, the states of Nevada and Utah, and the USFWS define threats and stressors differently (Nevada Wildlife Action Plan Team 2012, Utah Division of Wildlife Resources 2015, USFWS 2016). These

Table 6: Research agenda and priorities for Nevada and Utah springsnail and habitat conservation (this list is likely to change over time as new knowledge is incorporated).

Research Topics	Basic (B) or Applied (A)	Medium of High Priority	Examples, Reference(s)
Association, use, and importance of watercress *(Nasturtium)*	AB	Medium	---
Best management practices (BMPs) for population enhancement	A	High	Guerreri 2020
BMPs and technology for habitat rehabilitation	A	High	Stevens et al. 2016, Guerreri 2020
BMPs for *ex situ* propagation	A	Medium	Wells et al. 2012
Climate change impacts on springs ecology	AB	Medium	Morrison et al. 2013
Compatible livestock grazing management practices	B	High	Guerreri 2020
Competition impacts of non-native Mollusca	AB	Med-High	Rogowski and Martinez 2011
Distribution and population status of Nevada and Utah springsnail poplations and taxa	A	Med-High	Annual SCT reports
Ecological role of springsnails	B	Medium	Martinex and Thome 2006
Enhanced conceptual, numerical and other groundwater modeling	A	Med-High	Pohlmann et al. 1998
Groundwater quality and quantity sustainabiility for springs	A	High	Pohlmann et al. 1998; O'Brien and Blinn 1999
Habitat use and diet	AB	Medium	Martinez and Thome 2006, Martinez and Myers 2008
Impacts of non-native predators on springsnail population dynamics	AB	Medium	Creed 1994, Scoppettone et al. 2005
Improving public and agency awareness about springs and springsnails	A	High	Abele 2011; this document
Improving public incentives for improved springs management	A	High	Casey et al. 2006; Paulich 2010
Improving springsnail taxonomy, especially those with wide distributions	B	High	Appendices A, E, F
Microhabitat improvement practices (e.g., adding firm substrata)	B	Medium	---
Niche segregation among co-occurring springsnail species	B	Medium	Rogowski and Martinez 2011

Population and habitat assessment protocol testing and improvement	A	High	Martinez and Sorensen 2007
Population dynamics and demography of springsnail species	AB	Medium	Martinez and Thome 2006
Springs distribution and associated characteristics in Nevada and Utah	B	High	Springs Stewardship Institute 2019; SCT collaborators
Springsnail diseases and parasitism	AB	Low	Taylor 1987
Springsnail responses and adaptability to decreased discharge and associated habitat changes	AB	High	Morrison et al. 2013
Springsnail responses to climate changes	AB	High	Morrison et al. 2013
Springsnail taxonomy, especially those with wide distributions	B	High	Appendices A, E, F
Synecology of selected springsnail species	B	Medium	Sada 2007

differences necessitate development of a crosswalk through which different terms and definitions related to threats and stressors are related (Appendix C).Specifically, the crosswalk relates risk factor terms used in this document by the Nevada Department of Wildlife to those of describing the threats and stressors identified in the Utah Wildlife Action Plan Levels 1 and 2, to the five following listing criteria used by the USFWS.

USFWS Stressor Elements

Scope: The geographic and temporal extent of stressors affecting the range of the target species are scored as the following: "I" (Insignificant - stressor's geographic extent negligible); "Sm" (Small - <10% of population's potential range); "M" (Moderate - 11-30% of population's potential range); "Si" (Significant - 31-60% of population's potential range); or "VS" (Very Significant - > 60% of population's potential range). The following are used to describe temporal extent: "L" (Long-term - stressor expected to be persistent without intervention): or "S" (Short-term - stressor expected to dissipate on its own within <5-10 years).

Immediacy: The action time frame of the stressor, with the following used to describe immediacy: "F" (Future - effects anticipated in future); "I" (Imminent - effects occurring now); or "H" (Historic - effects already realized, but restorative action necessary).

Intensity: The capacity (strength) of the stressor to harm the species. The following are used to describe intensity: "L" (Low - minor reductions in range or population vitality (survival and reproductive capacity); "M" (Moderate - reductions in range or vital rates); or "H" (High - severe reductions in vital rates).

Exposure: The extent to which a target resource, individual springs-dependent taxon (SDT), or its habitat and the stressor overlap in space and time; the level of the total population exposed to that stressor. Levels of exposure are described as: "I" (Insignificant - level of exposure <10%); "Sm" small (10-40% of population exposed); "M" medium level of exposure (40-70%); "H" high (70-90%); "Ext" extreme (>90% exposed).

***Response*:** The change in species behavior, reproductive capacity or survival due to a specific stressor; the level of physiological/behavioral response to exposure to the stressor. The

following are used to describe response: "B" (Behavioral - startle, displace, etc.); "BNI" (Basic Need Inhibited - capacity to meet basic needs of feed/breed/shelter altered, possibly reducing growth or vital rates); "C" (Confirmed mortality or identifiable reduction in individual growth or vital rates); or "S" (Significant mortality or reduction in individual growth or vital rates).
Overall Risk Level: The above factors are used to calculate an overall risk level. This overall risk level integrates the scope, immediacy, and intensity of stressors and threats with the exposure and response of the species, measured at the population and species level. Combining stressor and threat assessment can be used to establish conservation action priorities. The following are used to describe the overall threat level; "L" (Low - no action needed at present); "M" (Moderate - action is needed); “H" (High - immediate action is needed); or "S" (Severe - immediate action is essential for survival of the population).

With basic agreement about the conservation lexicon (Appendix C), the signatories can collaboratively discuss agency responsibilities. Agencies, organizations, and/or landowners with spatial or legal jurisdiction for a springsnail population or its habitat will be responsible for monitoring and maintenance of that population, and will take the lead within the SCT on conservation of that population. Appendix D provides a description of SCT cooperating agencies prioritization of the scope, immediacy, intensity, exposure, response, and overall threat levels for risk factors that threaten springsnail populations and their habitats under that agency’s jurisdiction. Appendix D defines conservation measures and expected benefits to springsnails in relation to the resolution (local or far-field) of each described risk factor.

Conservation effectiveness requires definition of practical metrics of success, which vary by population, risk factor, and landowner. Appendix D provides a synopsis of metrics of success for each of the recognized threats, as well as a reporting schedule to enable the SCT to convey results of the program to the signatory agencies. The SCT will collaboratively produce annual and five-year review reports with representatives of the participating organizations to present progress on springsnail conservation in Nevada and Utah.

Risk Assessment

The SCT will continue to refine conservation risk assessment for each springsnail species. A quantitative approach to risk assessment (Appendix E) is proposed based on a hierarchy of information involving questions, assumptions, contributing factors, and potential research needed to refine understanding of threat and stressor risk factors. It is based on a scoring system to calculate comparable, unbiased risk scores to provide springsnail managers with a refined, quantitative scoring, to enable managers to document subtle improvements to populations and habitats resulting from management actions. The SCT will refine this prioritization process to use new and existing information and ensure the adequacy of information on status, stressors and threats, urgency, priority, and the required management actions for each springsnail population in Nevada or Utah. The general plan for these calculations is provided in Table 7, and detailed calculations will be performed for each population of each species in Appendix E.

Table 7: Overview of questions, assumptions or issues, factors, calculations, and assessments needed to establish and prioritize individual springsnail population, species, and habitat stewardship actions (Appendices A, E).

Priority-Step	Step	Question, Issue, Description
1	Question	What is the quality of information on the species and its habitat condition and trend?
	Assumption	Current information quality is generally assumed to be low
	Factor	The number of populations reported and its trend in abundance over time
	Factor	The size of each population and trend over time
	Factor	The date of the most recent survey that reported the population
	Research	Conduct standardized surveys database, enter the data into the database, and report the results
	Calculation	Demographic trends within and among populations over time
	Assessment	Evaluate results and determine appropriate actions.
2	Question	What is the susceptibility of the species to population decline or extirpation due to limited representation, redundancy, or resiliency or unknowns thereof?
	Issue	Susceptibility is unknown (information needed)
	Factor	Species susceptibility due to representation (degree of endemism)
	Factor	Species susceptibility due to redundancy (number of populations)
	Factor	Species susceptibility due to resiliency (usually moderate)
	Calculation	Calculate species susceptibility as the sum of weighted factor scores
	Assessment	Evaluate results and determine appropriate actions.
3	Question	What is the overall condition and vulnerability of the occupied habitat?
	Issue	Habitat condition and vulnerability is unknown (information needed)
	Factor	Determine current condition and causes of local (near-field) habitat (vulnerability)
	Subfactor	Determine significance of impacts on local habitat
	Subfactor	Determine significance of possible future impacts on local habitat
	Research	Determine habitat research needs and feasibility of habitat remediation

Priority-Step	Step	Question, Issue, Description
	Calculation	Calculate local habitat vulnerability as the average weighted sum of present and future vulnerabilities of each occupied habitat
	Factor	Determine current far-field habitat vulnerability
	Subfactor	Determine significance of far-field impacts on habitat
	Research	Determine far-field habitat research needs and feasibility of remediation
	Calculation	Calculate far-field habitat vulnerabilities as the (weighted) sum of present and future vulnerabilities of each occupied habitat
	Calculation	Calculate the sum of the local and far-field habitat vulnerabilities of all occupied habitats
	Plot	*Plot:* Visualize the vulnerability of the overall assemblage and habitats to determine which species are at greatest risk in the lowest quality habitat.
	Assessment	Evaluate results and determine appropriate actions.

Effective risk assessment first involves consideration of information quality, and the availability of information on the vulnerability of each population and habitat within and among species (Table 7; Appendices A, E). Risk assessment of the quality of information for a species and its habitats involves recording the first and most recent detection dates from surveys, the total number of reported populations (i.e., springs and springbrooks in which a species has been reported), habitat quality changes over time, and which states and agencies have responsibility for those sites. Inventory data from site visits (local data), expert opinion provided by the inventory staff, and laboratory analyses of far-field threats are entered into Springs Online and used to score each population of each species. Using this approach, the SCT will score information quality on a very poor, poor, medium, good, and high scale. Individual population and habitat risks are scored on a scale of 1 (no risk) to 10 (highest risk, the habitat or population has been extirpated) to generate both species- and a habitat-based informational risk quality scores. The average score for a species, and its habitat risk score are calculated and used to inform both the responsible agency and the SCT. The proportion of the total is expressed as the percent habitat risk of all populations, and species risk is the average percent of risk among all populations. A population that is abundant and apparently healthy might receive a population risk score of “2”. Extirpated populations are given a score of “10” indicating highest level of risk. A population that persists at a highly degraded site might receive a habitat risk score of “8”. The Springs Online database will be improved to provide automated data synthesis and archival, graphing of results for visualization, and reporting of risk scores and priorities among agency landscape jurisdictions.

The Strategy focuses on developing sufficient information to guarantee the persistence and improvement of springsnail populations over time in Nevada and Utah. If information quality is high, consideration of a population’s redundancy, resiliency, and representation can be quantified (Table 7; Appendix E). For target springsnail species: *redundancy* (ability of a species to withstand catastrophic events) is assumed to vary from low to moderate due to the generally restricted number of populations; *resiliency*, the ability of its populations to withstand stochastic disturbance events, is assumed to be low in relation to groundwater depletion but moderate in relation to site disturbance, with potentially fast population recovery; and *representation*, the ability of a species to adapt to changing conditions, is low due to the narrow tolerance range of springsnails to specific water quality and habitat conditions. For these reasons, springsnail conservation requires protection of their springs and springbrook habitats because springsnails can rarely be successfully translocated or even propagated in settings external to their native springs. Thus, risk assessment of both the species and its habitat is needed. Quantification of variables contributing to these three elements of population integrity will allow the SCT to evaluate individual species changes and program success over time.

Using the quantitative and comparative risk assessment approach (above), technical information can be provided to the managing agencies to determine conservation priorities and population- and site- specific management needs. These refinements will readily reveal species and habitat risks for individual agencies and spatially across Nevada and Utah. Such information can be used to prioritize annual work plans and reporting for individual agencies and the SCT. Analysis of patterns among risk variables may refine understanding of the utility and inter-relationships among inventory variables and, as data are compiled, it will be possible to refine the monitoring protocols. This risk assessment analysis approach is expected to continue to evolve, and will provide for informed discussion among agencies and landowners to implement stewardship of springsnails and their habitats.

Objective 3: Conserve Habitats to Ensure Species Persistence

Management actions already have been shown to improve habitat and species protection. For example, elongate Mud Meadows pyrg (*Pyrgulopsis notidicola*) occurs only in Soldier Meadows in Nevada, but was removed from USFWS Candidate Species list (2012b) following an annual appraisal of its status. That species had been placed on the Candidate List in 2002 because of potential hot springs recreational use impacts. However, the BLM, which manages Soldier Valley, implemented several management actions that reduced habitat threats. In addition, further inventory revealed at least three additional populations of the springsnail, thus the species is less vulnerable to extinction than previously thought. Nonetheless, continued monitoring is needed to provide habitat and population information that can be used to inform managers about how to prevent or remediate future impacts.

The SCT will work to ensure the integrity of all springsnail populations and their habitats by continuing to inventory and monitor springsnail populations, manage information on those species and habitats, and by conducting maintenance, enhancement, and restoration projects, as needed and practicable. Achieving this third objective will require information that identifies the individual species habitat needs, a well-informed inventory, monitoring, and information management program, a well-organized planning and implementation program conducted under guidance from the SCT. The SCT will facilitate outreach by providing compelling incentives to private landowners to improve springsnail stewardship.

An initial two-stage quantitative, comparative prioritization process is needed to help guide the SCT and individual agencies incorporate technical information (e.g., monitoring data) to conservation planning and implementation (Paffett et al. 2018). This process involves: 1) presentation of scientifically credible information on the distribution, status, risks, and trends in condition of the target springsnails and their habitats to the SCT by agency technicians and experts (Appendix E); and 2) prioritized management planning and actions by the responsible agencies, with advisement by the SCT. While inventory and monitoring data support the technical elements of springsnail and habitat information management (Table 7, Appendix E), the agency and SCT planning phase must involve collaborative discussion about potential NEPA compliance, interactions among collaborators, funding, logistical and other management practicalities, and the likelihood of success of the actions. A quantified suite of questions, assumptions, factors, and calculations for determining and prioritizing springsnail species and habitat vulnerabilities will help establish management priorities based on the technical information compiled and assessed under Objectives 1 and 2 (Table 8). Using data from the risk assessment prioritization spreadsheet data for each target species (Appendix E) and data from Tables 7 and 8, the SCT will annually review and review information acquisition, priorities, and conservation implementation tasks for the coming year. The SCT will recommend pre-treatment surveys, as well as monitoring of treated sites to ensure programmatic purposes are achieved and subsequent treatments are better informed.

Although compatible uses of springs can be achieved for many springsnail species, some species with presently healthy populations are restricted to only one or a very few locations, and cannot be sustainably translocated elsewhere. Because of the lack of redundancy and resilience of those species, they may warrant consideration for listing despite planned management efforts by the SCT. Listing will protect species from proposals to develop or alter their habitats, future actions that the Strategy cannot presently foresee.

Objective 4 – SCT Organization and Coordination

The SCT will develop and coordinate efforts to conserve springsnails and their habitats in Nevada and Utah. The SCT meetings will be chaired by a steering committee, consisting of an elected chairperson, a vice chairperson, and the previous chairperson, with at least one member of the steering committee from each state. The chairperson will be elected by the SCT membership and will hold the office for two years, and may retain his/her position for up to three terms (a total of six years). In addition, the SCT will nominate a secretary or facilitator to assist with communications and meeting coordination. SCT meetings will be held at least on an annual basis, and will be conducted according to Robert's Rules of Order. Specific meeting details and an agenda will be provided at least 30 days prior to each meeting, to allow SCT members to plan appropriately. The SCT will operate on the basis of consensus whenever possible, and only resort to 2/3 majority voting by members in attendance when necessary to resolve non-consensus conflicts. Non-SCT members attending the meeting will be invited to provide comments at the conclusion of the meeting. Notes and presentations from all meetings and proceedings will be archived.

The suite of objectives, strategies, and actions (Table 1) to be considered at each SCT meeting is summarized in the program diagram (Fig. 7). The SCT will coordinate the program

Table 8: Approach through which the SCT intends to adaptively manage springsnail conservation to achieve the goals and objectives of the Agreement.

Step	Action
1	Initiate implementation of SCT conservation objectives, strategies and actions through annual meetings to achieve program goals.
2	Update or initiate taxonomy, distribution and threat inventories and habitat monitoring program.
3	Periodically review SCT conservation goals, objectives, available information, strategies and actions, and adjust as necessary based on updated information.
4a	Prioritize species and locations for implementation of conservation actions
4b	Identify and prioritize research or monitoring needed to inform management actions.
5a	Initiate prioritized site-specific actions to reduce or eliminate threats and/or
5b	Complete identified research or management projects.
6	Monitor populations and habitats to determine trends, responses to environmental conditions, potential impacts of monitoring on the population and habitat, and the effectiveness of conservation actions. Manage the information.
7	Analyze and evaluate monitoring and research results to determine progress towards attainment of conservation objectives.
8a	If results support objectives, predicted responses, and desired outcome, return to Step 5 (a or b).
8b	If results do not support objectives or desired outcome, return to Step 3.

objectives, strategies, and actions to achieve the Agreement goal. Coordination may be facilitated by *ad hoc* committees charged with: 1) coordinating administration, membership, communications, and funding; 2) technical and database coordination (e.g., inventory, research, monitoring, information management, annual and five-year report preparation and presentation); 3) education and outreach; and other committees. Ad hoc committees may engage invited external experts, as needed.

Annual SCT meetings will be held alternating between states and between December and February each year to: 1) review the structure and content of the Strategy in relation to the Agreement; 2) review the past year's information and the annual SCT report to the signatory agencies; 3) prioritize monitoring, research, conservation, information management activities; 4) plan activities for the coming year; 5) discuss challenges, contingencies, and funding issues that may arise; and 6) elect new steering committee members. Prior to each annual SCT meeting, collaborating agency staff will enter field data and reports into the database, to ensure those data and reports are archived into the data and reference libraries. Annual field data will be entered by 1 December each year by the entity collecting those data or their representatives, with sufficient time for quality control, integration, and annual reporting to the

SCT and the signatory agencies by the end of the calendar year. Then at each annual meeting, the SCT will assemble and evaluate the conservation actions taken by each signatory organization. Annual rview of the above information will allow the SCT to document program success each year, and will help inform work planning for the up-coming year.

The SCT will regularly communicate with the Agreement signatories, and provide evidence of progress through the annual report. For public functions, the SCT will communicate to the public through agency outlets. Such communications may include: 1) advertisement regarding SCT functions, such as the state-of- knowledge symposium (Objective 1); 2) press releases on program progress (e.g., annual progress reports); 3) presentations at public or scientific meetings; and 4) inter-agency collaborations that warrant public attention (Objective 5).

The Agreement and the SCT will use adaptive management as a stewardship approach. Adaptive management is the structured process of making well-informed decisions in the face of uncertainty. It involves stakeholders and participating scientists mutually recognizing issues, implementing management actions, reviewing monitoring data on the success of those actions, and providing feedback to improve management as well as informing others about lessons learned (Holling 1978, Walters 1986, Bormann et al. 1999). The essential steps of the SCT adaptive management process include the steps illustrated and described in Fig. 7 and Table 8.

In comparison with broad societal actions, such as conservation of large landscapes or wide-ranging iconic species, springsnail population and habitat conservation involves relatively few stakeholders (typically one or very few agencies, tribes, and private landowners). If the supporting aquifer is relatively intact, and if stakeholders can reach consensus on management options and actions, stewardship planning and implementation benefiting all parties and the resources may be relatively easily achieved (e.g., Paulich 2010, Paffett et al. 2018).

Objective 5: Education and Outreach for Springsnail Conservation

While springs are often compelling conservation foci for the public, springsnails have thus far attracted limited public attention. Hence, promoting the ecological integrity of springs may engender more public enthusiasm that will springsnails. The SCT will coordinate communication, education, and outreach about springsnails and their habitats to the public, private landowners, the scientific community, the signatory agencies, and to other states in the Great Basin. As a first step, the SCT will develop and pilot test its messaging to the public. For example, “What’s good for springs is good for all things” might be an effective campaign slogan for the Strategy. The messaging will then be refined and checked before it is publicized. The results will be carefully monitored to ensure the messages are being received in a fashion that supports springsnail conservation. The SCT will coordinate and participate in presentations to K-12 schools, lesson planning, presentations and lectures to college students and the public, and scientific publications on springsnail ecology and conservation. The results of this messaging and consistent, rigorous efforts by the SCT to reach out to the private sector will help increase public enthusiasm and involvement for protection for these diminutive, but exquisitely adapted organisms, as well as springs ecosystems in general and the many species they support.

The SCT will develop strong partnerships with private springsnail stewards, and explore and implement incentives to improve springsnail conservation actions by private parties. The SCT will seek out private spokespersons for improving springs and springs biota protection.

Throughout the life of the Agreement, the SCT also will work with Conservation Districts to achieve springsnail conservation among ranchers and other private stewards.

7. Conclusions

The Conservation Strategy for Springsnails in Nevada and Utah is designed to use credible scientific and management information to enable the collaborating agencies, organizations, and the public to improve springsnail and springs habitat conservation. This Strategy relies on the involvement of each Agreement signatory steward or agency in adaptive management to support or conduct compilation and interpretation of high-quality distribution, status, and risk assessment data to prioritize, plan, implement management actions, and provide monitoring feedback to ensure project success. However, a large array of uncertainties exists around conservation of springsnails and their habitats in Nevada and Utah. These uncertainties fall into four categories: (1) basic information on distribution, ecology, status, and trends; (2) population and habitat sustainability, including habitat rehabilitation options; (3) policy and inter-agency commitment and public outreach to sustainably manage springsnail populations; and (4) unpredictable impacts of climate change coupled with increased human appropriation of springs ecosystem goods and services. While (1) can be learned through field inventories, (2) will require applied and well-documented research and experimental management actions. Uncertainty in application of policy and outreach (3) is a function political will that, coupled with (4) climate change and societal processes, may exert unanticipated impacts on the societal and policy landscapes.

Consistent with the goals of this Strategy, monitoring actions and conservation measures implemented by SCT members will follow with the mandates and missions of the collaborating agencies and the concepts of adaptive management (Appendices C, D). The effectiveness of springsnail inventory, monitoring, conservation measures, and information management will be periodically reviewed and evaluated by the SCT, and by unbiased, external reviewers. Such review will help keep the actions, data collection and information management consistent with developing concepts and available technology. Based on such evaluations, appropriate modifications to strategies and actions will be made to improve and ensure scientific rigor and the efficacy of conservation measures. Support from signatories is needed to ensure successful implementation of adaptive management for springsnail conservation. The SCT is charged with addressing all of these complex issues over the next decade, a mission that requires insight, collaboration, flexibility, and dedicated, transparent agency support to achieve the goals of the Nevada-Utah Springsnail Conservation Agreement. This Strategy is regarded as an adaptive, living document, subject to refinement as additional information, technologies, and understanding of Nevada and Utah springsnails arises.

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APPENDICES

APPENDIX A: SUMMARY REPORTS ON SPRINGSNAIL SPECIES IN NEVADA AND UTAH

(Available online for SCT members through a password-protected link on the MNA Springs Stewardship Institute website)

Appendix B: Recommended Springsnail Inventory, Monitoring, and Collecting Protocols

Donald W. Sada, Robert Hershler: June 2019

Introduction

More than 100 new species of crenobiontic springsnails (Superfamilies Truncatelloidea and Cerithioidea) have been described from the Great Basin and Mojave Desert in the past century (e.g., Hershler 1998, 1999; Hershler and Sada 1987, 2002, Hershler et al. 2014a, b). Some species are known from a single spring, others from several springs, and some are apparently widespread, occupying hundreds of springs over large areas (Hershler 1998, Sada and Vinyard 2002). Springsnail distribution is known mostly from springs inventories and taxonomic collections made in the latter half of the Twentieth century. More recent surveys have documented population losses as well as a number of previously unknown populations. Tallies of Great Basin and Mojave Desert springsnail population losses are summarized in Sada and Vinyard (2002) and Sada and Lutz (2016), and additional, previously unknown populations are known from Sada (field notes) and fieldwork led by Sada and supported by Abele (2011). A tiered set of three protocols, summarized herein, provides reliable, repeatable, and non-lethal methods to assess spatial and temporal variability in springsnail abundance and environmental characteristics of their habitats. The three tiers are increasingly quantitative, each using a basic springsnail inventory form to record date, surveyor, location (site name, site ID number, state, county, georeferencing), photographs, and a springs ecosustem habitat condition assessment (Appendix B.1). These protocol elements were used by Sada and Hershler to compile information about physicochemical and habitat conditions at essentially all Great Basin and Mojave Desert springsnail habitats, including more than 2,000 springs. This information has now been assembled at >3,000 springs acrpss the Southwest (e.g., Sada and Pohlmann 2007; Sada and Jacobs 2008 a, b, c; Sada 2013 a, b).

The monitoring protocols presented here consist of three levels of survey that require increasing effort (and time) to compile increasingly quantitative information on habitat characteristics and springsnail abundance. Tier 1 requires a basic reconnaissance survey of <15 minutes/site to determine if a population is present and to evaluate habitat conditions. Tier 2 includes all elements of a Tier 1 survey, and documents water depth, wetted width, substrate composition, percent of bank and instream cover, field water quality parameters (water temperature, pH, electrical conductance), and the downstream extent of occupied habitat. Tier 3 includes the elements of the lower tiers, and additionally quantifies springsnail abundance and physical characteristics of the springbrook habitat at equally spaced transects that extend from the spring source to the downstream extent of springsnail habitat occupancy. All tiers use the Springsnail Survey form (Appendix B.1) to record a base of information. Information compiled for all tiers is indicated by '***' on the form. All other elements are recorded in Tiers 2 and 3, following guidelines shown below.

These protocols are based on a long history of sampling springsnails and the recognition of life history characteristics, habitat use, and factors that have adversely affected the size and status of springsnail populations. The protocols incorporate the following elements:

- Surveyors must be qualified to visually identify springsnails. Without training it is easy to confuse them with other small gastropods (e.g., *Physa*, *Lymnea*, etc.)
- Because springs names are local and change over time, all monitoring must identify each spring by spring name and a numeric identifier used in the Springs Stewardship (SSI) Springs Database. New springsnail localities should be georeferenced, named and SSI should be notified to provide a numeric identifier.
- The habitat condition assessment is based on disturbance categories relative to the structure of benthic macroinvertebrate (BMI) communities. Sada et al. (2015) and Keleher and Rader (2008) found significant differences in BMI community structure between qualitative assessments of undisturbed/slight disturbance, and moderate and high disturbance that is a component of all surveys. This assessment evaluates how disturbance relates to springsnail habitat threats and assumes that snail abundance is reduced by human disturbance.
- Non-lethal sampling methods are necessary, but collection for genetic and morphological analyses may be needed.
- Populations can exhibit wide seasonal fluctuations in size. Therefore, abundance is best determined from May – October when populations are large and adults are present. Determining density is time-consuming and not necessary to determine status. Status can be readily achieved by assessing ‘relative abundance’ that provides repeatable information that can be quickly collected. Sada (2016) calculated these measures to assess the status of on 16 springsnail species among more than 120 populations in Nevada, California, and Utah.
- As with many springs-dependent taxa, springsnails typically occur only near spring sources and within a defined distance downstream. This distance varies widely between taxa, populations, and habitats.
- Each taxon appears to have a specific habitat preference based on physicochemical features, such as temperature, water velocity, substrate size, water depth, and affiliation with vegetation, particularly water-cress.
- The protocol requires that the surveyors be knowledgeable about the factors that can affect the ecological integrity of springs ecosystems, and (for comparative purposes) the factors that characterize reference and naturalizing springs. This is necessary to relate variation in springsnail abundance with human and natural factors influencing conditions of their habitats and abundance.
- Caution must be exercised during each sampling event to prevent translocation of organisms between springs (see sample protocols for direction to sanitize equipment). Also, it is important to avoid walking in springbrooks, which causes mortality through trampling.

Survey Equipment

Field equipment needed to conduct springsnail surveys is listed below. All of these items are needed to conduct Tier 3 surveys, and the symbol '*" denotes equipment needed for Tiers 1 and 2.

- AAppendix B.1 datasheet on write-in-the-rain paper.
- *GPS
- *Digital camera.
- *1-mm mesh kitchen sieve with smooth interior edges (smaller mesh sizes are needed for some species, e.g., *Pyrgulopsis notidicola* in Soldier Meadow).
- *Plastic (e.g., Tupperware) container.
- *Glass binocular magnifier headset to enable surveyors with poor vision to differentiate springsnails from other gastropods.
- Wadable stream current velocity meter with top-setting rod (e.g., Marsh McBirney Model 2000, Swoffer Model 2100, or other flow measurement equipment (Stevens et al. 2016).
- Metal meter stick to measure springbrook wetted width.
- Maps, pencils, paper, etc.

Tier 1 Monitoring

At this monitoring level, elements such as springs ecosystem name, georeferencing, and habitat condition are recorded. These variables are identified by "*" on the Spring Survey Form (Appendix B.1); recording the spring name, location, etc., and habitat condition. Springsnail sampling is limited to sampling of springsnails in the upper 10 m of springbrook. Samples are collected using a 15 cm (6 in), 1 mm mesh kitchen sieve or aquarium net. Use the sieve or net to gently roil the substrate and vegetation for ~ 3 seconds at no fewer than 10 randomly selected locations in the reach. The contents of the net are placed in a 15 X 15 X 5 cm (6 inch X 6 inch X < 2 in) deep 'Tupperware' container containing clear water that is ~1 cm deep. Count the snails collected, and either record the number caught during each effort in the Pyrg/Try columns of Appendix B.2 or categorize the mean number captured as scarce (< 6/sample), common (6-20/sample) or abundant (> 20/sample). Springsnails are returned to the springbrook within minutes of being collected.

Tier 2 Monitoring

Tier 2 monitoring is a blend of qualitative and quantitative assessments. All elements shown on the Spring Survey form (Appendix B.1) are recorded for Tier 2 (including elements identified by * and **. Tier 2 focuses on the upper 50 m of springbrook where water temperature and electrical conductance (EC) are recorded as close to the spring source as possible and physical characteristics of the springbrook are estimate during a visual survey. The downstream extent of springsnails is recorded by GPS or from a USGS 1:24,000 map.

Tier 3 Monitoring

Tier 3 surveys can be used to assess management effectiveness and population status. These surveys include elements that quantitatively sample spring environments occupied by springsnails, and assess springsnail abundance in the springbrook along the gradient from the source to the downstream-most extent of distribution or the springbrook terminus. Information collected at each spring includes data listed in Appendix B.1, following the guidelines created by Sada and Pohlmann (2006) for the U.S. National Park Service. Those guidelines were also used to survey approximately 3000 springs in Death Valley, Joshua Tree, Big Bend, Carlsbad Cavern, and Organ Pipe National Parks, and Grand Canyon-Parashant National Monument and Lake Mead National Recreation Area, (Sada and Pohlmann 2007; Sada and Jacobs 2008 a, b, c; Sada 2013 a, b). This protocol was the basis for springs data collected by Hershler, Sada, and Vinyard during early springsnail inventories. Directions to complete this form are described in Appendix B.3. To reduce paper and facilitate data organization, data that qualitatively assesses springsnail abundance and spring brook characteristics are printed on the back of this form. Both forms will be completed following description of survey elements that is summarized below.

Tier 3 surveys provide quantitative information describing physico-chemical characteristics of springbrooks and the relative abundance of springsnails along a gradient from the springs source to their downstream limits. As in the lower sampling tiers, the area of habitat occupied by springsnails in each springbrook is determined using a 1 mm-mesh kitchen sieve to record the number captured during a 3 second sampling of approximately 100 cm^2 of habitat at evenly spaced intervals along the occupied habitat. Collections are made sequentially at springbrook right, center, springbrook left, then center up each springbrook. Springsnails are to be placed in a water-filled tray, counted, then returned to the springbrook within minutes of being collected (sampling with replacement). A maximum of 5 samples will be collected from springbrooks <50 m long, a maximum of 10 samples will be collected from springbrooks 50-100 m long, and a maximum of 20 samples from longer springbrooks. This will quantify the number of springsnails captured during equal sample efforts and provide information to assess their relative abundance and variability in abundance along a springbrook gradient.

Springsnail abundance, distribution, and occupied habitat are examined by determining the length of occupied springbrook, assessing springsnail abundance, measuring springbrook wetted width, maximum water depth, and mean current velocity, and estimating the percent of emergent and bank vegetation across transects.

A maximum of 5 transects are placed in springbrooks < 50 m long, a maximum of 10 in springbrooks > 50 m and < 100 m long, and a maximum of 20 in longer springbrooks. This number of transects should be modified accordingly where dense riparian vegetation prevents access to springbrooks and removing it will cause excessive disturbance. Transects are to be placed only where access is possible in these situations. Springsnail abundance at each transect is determined by roiling substrate and vegetation and capturing springsnails during 3- seconds of sampling approximately 100 cm^2 of habitat using a sterilized 1 mm, 12 cm diameter kitchen sieve. Quickly place all springsnails collected in a sample in a water-filled tray, count each individual and immediately return them to the springbrook to minimize stress and prevent mortality. Sequentially collect samples at springbrook center, then along the left then right bank along consecutive transect as you move upstream. Calculate the mean number of springsnails captured by these ‘grab samples’ in each springbrook to create a ‘catch per unit effort (CPUE)’. For mean CPUEs less than 6, springsnails are categorized as ‘scarce’, they are categorized as common with values greater than 6 and less than 20, and as ‘abundant’ when CPUEs are greater than 20. The number of springsnails in each of these categories approximates observations made during historical surveys by Hershler, Sada, and Vinyard. Although this is a qualitative assessment of their abundance, it quantifies the amount of occupied habitat in each spring, qualitatively assesses springsnail abundance, and quantifies variability in their abundance along springbrook gradients.

In springs occupied by more than one species in a single genus (usually the genus *Pyrgulopsis*) and where the site can sustain a large collection, collect and preserve approximately 200 springsnails (see collecting techniques in next section) and take the collection to a laboratory where a microscope can be used determine the relative abundance of each species in the assemblage. Where different species in the same genus occur, it is relatively easy to compare shell morphology and determine the proportion of each taxon in the assemblage.

Data elements to be recorded at each spring for Tier 3 surveys are provided in Appendix B.4, and described below:

- <u>Spring Name</u> The name of individual springs. In spring provinces (clusters), this may be ‘Point of Rock Spring A, Point of Rocks Spring B. Names will follow the convention used in the Springs Stewardship Institute database.
- <u>Spring ID No.</u> The number assigned to individual springs in the Springs Stewardship Institute Database.
- <u>Date</u> the survey is conducted. Record this in the ‘month/day/year’ format.
- <u>Lead Person</u> (Surveyor) conducting the spring survey by first letters of their given and middle names and surname (e.g., JD Smith).
- <u>Species</u> = the springsnail taxa occupying the spring. If more than one species in the spring, note which taxa is ‘Sp. A’, ‘Sp. B’, etc.
- <u>Distance</u> = the location of the sample (transect), in meters, from the spring source.
- <u>WW</u> = the wetted width (in cm) of the springbrook at the transect, measured along the transect and perpendicular to the thalweg (the deepest point in the channel).
- <u>WD</u> = the maximum water depth (in cm) of the springbrook along the transect.
- <u>CV</u> = the mean water column velocity (cm/sec) at springbrook center along the transect.
- <u>%ECOV</u> = the estimated % cover to the springbrook provided by emergent vegetation.
- <u>%BCOV</u> = the estimated percent vegetative cover of the springbrook banks.
- <u>Pyrgs/Try, etc.</u> = the number of individual Pyrgulopsis (Pyrgs) and Tryonia (Try) collected during CPUE samples for each springsnail species collected in each kitchen sieve along the transect. Where more than one species in a genus occurs, count the total number of springsnails captured and adjust following laboratory examination to determine the relative abundance of each taxon in the assemblage.
- <u>Associated aquatic species of plants</u> (e.g., watercress), invertebrates (other Mollusca, aquatic insects)

Specimen Collection and Preparation

Due to the difficulty identifying springsnail species morphologically, specimen collection is often needed to verify population status. At newly discovered populations, collecting specimens is needed for both genetic analysis, as well as dissection for morphological analysis of soft parts (see collection protocols, below). Populations when discovered often are large; however, collecting should only be conducted if the population can withstand removal of 100 specimens.

Genetic Analyses

For genetic analyses, 25 springsnails are individually placed in paper envelopes, and the envelopes are labled with collection locality data, the date, and the collector's name. Each of the 25 envelopes is placed in a desiccator to dehydrate the sample. The dried samples are stored at room temperature and delivered to the SCT' preferred genetics laboratory.

Morphological Analyses

Hershler and Liu (2017: 5-6) provide the following guidance on specimen collection protocols.

"Freshwater truncatelloidean snails usually are locally abundant, enabling ready collection of sizeable samples (i.e., >100 specimens). A portion of each sample should be directly preserved in concentrated (90-100%) nondenatured ethanol; half of these specimens can be subsequently (air-) dried and designated as shell vouchers while the rest can be retained (in ethanol) for possible DNA analysis. The remaining portion of the sample should be anesthetized (relaxed) with menthol crystals (prior to fixation and preservation) to facilitate examination of soft parts required for identification. Menthol is an organic compound obtained from mint plants that is readily available in crystalline form from chemical supply houses. Relaxed material is particularly useful for study of the penis, while pertinent details of the female genitalia usually can be obtained from contracted specimens that were directly preserved in ethanol. Snails should be relaxed in a large container (e.g., a 1-pint [473-ml] Mason jar) that is nearly filled with habitat water and kept cool and out of the sun. A small quantity (about half a teaspoon) of powdered menthol crystals should be sprinkled over the water surface, after which the container should be capped and left undisturbed. The snails usually require about 13 hours for proper relaxation, although some species (e.g., Jackson Lake springsnail) may require considerably more time. Once the specimens are anesthetized, at which time the head-foot is well extended and insensitive to touch, most of the water should be decanted and dilute formalin (10% of stock solution) should be slowly added. After 4-6 hours of fixation, the material should be rinsed and preserved in 70% ethanol.

Alcohol-preserved snails are separated from their shells by placing them in a small quantity of concentrated hydrochloric acid. The appearance of the distal portion of the oviduct—whether it is glandular…or thin-walled and containing brooded young…can be readily determined without dissection. The bursa copulatrix can be viewed by pinning the animal, cutting the mantle along the left side of the head-foot, and pulling this tissue over…to expose the oviduct and associated structures...The penis is attached to the "neck" of the snail behind the snout and usually extends beyond the mantle edge…; both the upper (dorsal) and lower (ventral) surfaces of the penis should be examined for glands, which are relatively large and quite obvious; the internal penial glands of amnicolids are clearly visible in appropriately prepared specimens… We recommend that workers practice the methods of anesthetizing, preserving, and dissection using (commonly found) snails before applying them to essential specimens."

APPENDIX B.1: SPRING SURVEY FORM TO ACCOMPANY SPRINSNAIL SURVEYS

*LEVEL: Tier 1 Tier 2 Tier 3 TIME SURVEYED: ___________

*FIELD NOTE #: ___________ *SURVEYOR: ____________ *DATE: __________________

*STATE: ___ *COUNTY: ________*SPG. NAME: ______________________________

*SPRING ID NO.: ____

*SOURCE GPS: Latitude: ____________ Longitude: ______________ ± m: ________

*PDOP: ______ *ELEVATION (M):_________ * ACCESS: _______

*NO. OF PHOTOS TAKEN:_____________

*SPRINGSNAIL SPECIES SURVEYED: *Pyrgulopsis* ____________ Pyrgulopsis ___________

Tryonia ______________ Other Species ____________________

*NEW SPRINGSNAIL LOCALITY: Y N

* EST'D SPRINGSNAIL ABUNDANCE: Absent Scarce Common Abundant

*OWNER: NPS USFS BLM TRIBAL MILITARY PRIVATE OTHER________________

*PRIVATE LAND OWNER NAME:______________________ ACCESS PERMISSION: GRANTED DENIED

**SPRING TYPE: HELOCRENE RHEOCRENE LIMNOCRENE DRY QANAT CASED WELL UNKN OTHER__________

**ESTIMATED DISCHARGE (L/MIN.)______________ SPRING BROOK LENGTH (M): _________________________

Vegetation Present:

Willow *Salix* sp.
Mesquite *Prosopis* sp.
Cattails *Typha* sp
Rushes Juncaceae
Spikerush *Eleocharis* sp.
Reeds *Scirpus* sp.
Salt Grass *Distichlis spicata*
Phragmites *Phragmytes australis*
Wild Rose *Rosa woodsii*
Grapevine *Vitis arizonica.*
Cottonwood *Populous freemontii*
Watercress *Rorippa sp.*
Palm Tree Arecaceae
Purple Loosestrife *Lythrum salicaria*
Sedge *Carex* sp
White Top *Cardaria pubescens*
Salt Ceder *Tamarix* sp.
Arundo *Arundo donax*
Other: ________________

**DOWNSTREAM SPRINGSNAIL GPS POINT: Latitude:________ Longitude:_____ Elev (m)________ EPE:_____(± m)

**LENGTH OF SPRINGBROOK OCCUPIED BY SPRINGSNAILS (m) ________ OCCUPIED AREA (m^2): ___________________

**MEAN WATER DEPTH (cm): ____________ AVERAGE WATER WIDTH (cm): __________

**TEMPERATURE (°C): ____________ CONDUCTIVITY (µS OR mS): _______________

**EMERGENT COVER (%): ___________VEGETATIVE BANK COVER (%): ___________

**SUBSTRATE (%): fines (<1 mm):___ sand (1 mm - 5 mm):____ gravel (>5 mm – 80 mm):_____cobble (>80 mm - 300 mm):___ boulder (>300 mm):__ bedrock:____

*OTHER IMPORTANT ANIMALS: NONE FISH CLAMS AMPHIPODS PULMONATES: OTHER: ____________________

**COLLECTIONS MADE: ____ MUSEUM DEPOSITED: _______________________

*OTHER NON-NATIVE SPECIES: ____

**OTHER VEGETATION: ____

**OTHER FAUNA: ____

*SITE CONDITION: naturalizing undisturbed slight moderate high

*DISTURBANCE: livestock recreation diversion residence drying fire flooding dredging other____________________

Cattle Horses Burros Sheep

*NOTES:____

____

State:	County:	Land Unit:	Site Name:	Date:	Start/End Times:	Observers:
Scale:	m or ft (circle one)	Notes:				

APPENDIX B.3: SPRINGSNAIL ABUNDANCE ESTIMATION - TIER 3 SURVEY FORM

Spring Name: ____ SSI Spring ID No: _________________ Date: ____________________

Surveyor(s): ____ Springsnail Species: ____

Surveyors:

_______________Species:

MEAN CATCH/UNIT EFFORT DURING SURVEY

Distance	WW	WD	CV	% ECOV	%BCOV	No. Pyrg.	No. Tryonia	Notes/Other

Appendix B.3: Instructions for Survey Forms

Description of Elements Recorded for Tiers 1 – 3 on the Springsnail Survey Form, Appendix B.1. All elements recorded for Tier 3 identify elements recorded for Tier 1, and ** for Tier 1 and Tier 2.

- ***Date*** the survey is conducted. Record this in the 'month/day/year' format.
- Lead Person (Surveyor) conducting the spring survey by first letters of their given and middle names and surname (e.g., JD Smith).
- ***Field Note Number.*** Standardize the number by including the initials of the person recording data followed by the last two digits of the year the survey is conducted, then, after a hyphen, followed sequentially by the number of the spring that has been surveyed by the lead surveyor during the year (e.g., for the 21st and 22nd springs surveyed during the year 2003, JS03-21, JS03- 22, etc.).
- ***The State*** where the spring is located. Record as the standardized abbreviation used by the U.S. Postal Service (e.g., CA = California, NV = Nevada, UT = Utah).
- *The County where the spring is located. This information is on maps, which can be reviewed in the office or the field.
- ***Spring Name.*** If unnamed, record it as 'unnamed' with a brief geographical description of its approximate location, e.g., 'unnamed spring in Willow Canyon'. If the spring is part of a province, identify it as 'Hardy Spring A', 'Hardy Spring B', etc.
- ***Location ID,*** which is an identification number for each spring as occur in the Springs Stewardship Institute Springs Database.
- ***Note important vegetation*** by circling the present species as listed in the upper left corner of the data sheet.
- ***Global Positioning System (GPS)*** location of the spring source. Record in decimal degrees latitude and longitude. If the source location cannot be recorded because GPS coverage is not possible or because the source is not accessible without seriously damaging riparian vegetation, record a location as close to the source as possible and note the approximate distance and direction of this location in the notes. Record the location in latitude/longitude coordinates. Record the estimated positioning error (EPE) as '+' the number of meters indicating accuracy of the GPS reading.
- ***Spring elevation*** in meters using GPS.
- ***Access.*** Record the ease at which the public could visit a spring. Categories 1 through 5. Category 1 = inaccessible sites, access only by cross-country hiking; Category 2 = sites that can be accessed only by arduous trail hike (e.g., > 5 miles); Category 3 = sites accessed by easy trail hike (e.g., 1 to 5 miles) and four-wheel drive vehicle; Category 4 = sites easily accessed by walking less than 1 mile or a two-wheel drive, high clearance vehicle; and Category 5 = sites immediately adjacent to high-quality gravel road or a paved road.

- ***Photos***. These photos should be taken to show the spring and its landscape context. The best photos overview the spring source and look downstream. Photos should be labeled by spring ID number, date, and spring name. Take additional photos to document conditions that are not captured in the general spring photo; label these with identifying information.
- ***Species surveyed.*** Record the species of springsnail surveyed in this spring.
- ***New or known locality. Circle*** to identify if this spring is a known or 'new' springsnail locality.
- ***Estimate springsnail abundance.*** Count the number of springsnails in each sample collected in the sieve. If the mean catch-per-unit effort (CPUE) is less than 6, record springsnail abundance as 'scarce', categorize abundance as common when values are greater than 6 and less than 20, and as 'abundant' when CPUE is greater than 20.
- ***Land ownership,*** as US National Park Service, U.S. Forest Service, Bureau of Land Management (BLM), tribal, military, private, or other (e.g., State lands, US Fish and Wildlife Service, municipality, etc., write out the name of the owner). This information is most easily determined using BLM Surface Management Maps (1:100,000 scale).
- ***Private Land.*** Record private landowner, and circle whether or not permission was granted to sample for springsnails.
- ***Spring Type,*** as: Rheocrene (a spring that discharges into a defined channel), Limnocrene (a spring that discharges into a ponded or pooled habitat before flowing into a defined channel), Helocrene (a marshy and comparatively shallow, not an open pond or pool), or other types as identified by Springer and Stevens (2009), and illustrated at: https://springstewardshipinstitute.org/ under the category "Springs Ecosystems". In many cases, springs have been altered by native peoples or settlers by excavating the source to create a pond or a Qanat (a horizontal tunnel excavated into a cliff face). Many springs will be dry when sampled. A number of Level I survey parameters need not be recorded as for dry springs, including water chemistry, water depth and width, substrate size distribution, and vegetative cover. All other parameters should be recorded. Also, record if a site is a mechanically dug well (usually with rock, metal, or plastic casing). Examples of disturbances that prevent ready identification of springs types include impoundment by dikes (anthopogenic limnocrenes), sources in a spring box, or dredging and filling to capture water in a pipe leading to a trough. Spring alterations and spring condition are assessed, and recorded in the Site Condition section below. If further description is necessary, it can be summarized in the Notes Section. See the Springs Stewardship Institute springs inventory protocols for additional guidance.
- *****Spring Discharge,*** estimated in liters/minute (L/min). It is difficult to estimate the discharge of most arid land springs because the springs are small, their discharging water is usually shallow and broadly and unevenly spread across wide area, and areas with moving water are often very limited. Therefore, measure the flow (see Stevens et al. 2016 for protocols). Springs discharge also tends to increase along the springbrook in the first several decameters, and dense vegetation may hide a springbrook and source from view. Accuracy also is relative term because discharge can changes throughout the day,

seasonally, or annually. Multiple measurements in different seasons increases the effectiveness of discharge measurement.

- *****Springbrook Length,*** measured in meters. For springbrooks less than 100 m use a tape to measure distance from the spring source (upstream limit of surface water) to the downstream limit of surface water. Pace the length for longer springbrooks.
- *****Length of Occupied Habitat.*** For springbrooks less than 100 m use a tape to measure distance from the spring source to the downstream limit of springsnails. For longer springbrooks, estimate this distance by pacing using a standard length of stride. Using the kitchen sieve, sample downstream until springsnails are no longer captured, then incrementally move upstream until they are captured. This capture site is recorded as the downstream extent of the population. Record the downstream extent using GPS.
- *****Mean Water Depth.*** Calculate this mean from the depths measured during the qualitative assessment of springsnail habitat.
- *****Average Water Width.*** Calculate this mean from transect widths measured during the qualitative assessment of springsnail habitat.
- *****Water Temperature.*** Measure the water temperature as close to the spring source as possible. Use a YSI Model 30, or similar, meter.
- *****Conductivity*** (also called electrical conductance, EC). Measure the water temperature as close to the spring source as possible. Use a YSI Model 30, or similar, meter.
- *****Emergent Cover.*** Estimate to the nearest 10 percent the vegetative, debris, or other material that arises within the water width and covers the water surface.
- *****Vegetative Bank Cover***. Estimate to the nearest 10 percent the proportion of springbrook banks that is covered by live vegetation.
- *****Substrate Composition.*** Qualitatively estimate in the occupied springsnail habitat using a Wentworth particle scale analysis, which describes the substrate by the proportional composition of materials, where materials are classified as: fines (<1 mm), sand (1 mm - 5 mm), gravel (>5 mm - 80 mm), cobble (>80 mm - 300 mm), boulder (>300 mm), or bedrock. Size is defined as the minimum particle size of substrate as measured on a two-dimensional axis, as would pass through a substrate sieve.
- *****Important animals and plants.*** Note the presence of plants and animals that may indicate habitat quality or aquatic persistence. These include amphibians, finger clams, amphipods, pulmonate gastropods, flatworms, fishes, ostracods, and non-native species.
- ****Site Condition.*** This evaluation qualitatively identifies: 1— disturbance factors stressing a spring and 2— the level of stress exhibited by each factor on the spring environment. Harsh chemical conditions are not noted in this section, but can be easily determined from water quality and conductance measurements. Sada et al. (2015) found that BMI community characteristics are correlated with most of these levels. Differences between slightly and undisturbed springs were not statistically significant, but differences between these levels and between moderately and highly disturbed were significant. Differences generally varied along a gradient of intolerant to tolerant taxa in occupying low to high disturbance springs, respectively. Determine factors causing stress by looking for evidence

of natural and human caused disturbances. Influences of flooding are indicated by location of a spring in the bottom of a gully, presence of a naturally incised channel, and usually a paucity of vegetation. The presence of pipes, dikes, or spring box indicates modifications for diversion. Abundance of hoof prints and droppings, and evidence of grazing indicates ungulate use of a spring. The presence of campsites and trash indicates recreation. The most common stressing factors are listed on the field form, and the appropriate factor(s) affecting a spring should be circled. Disturbance may be influenced by multiple factors, including trampling by intensive livestock occupation and diversion into a trough; recreation use along a springbrook that tramples vegetation and the springbrook is channelized away from areas used for picnicking. Circle each appropriate factor. If other factors are evident, circle 'Other' and briefly describe this effect in the Notes Section.

- ***Categorize*** each spring as undisturbed, slightly, moderately, or highly disturbed, and circle the appropriate category on the survey form. When entering data into a database, identify these categories as: 1 = undisturbed, 2 = slightly disturbed, 3 = moderately disturbed, and 4 = highly disturbed for easier data analysis. Level of disturbance are recored as follows:

  Undisturbed springs have not been detectably affected by recent or historical factors or activities. Any evidence of trampling, diversion, fire, or drying is absent. Since most springs have been altered by humans, drought, fire, or flood, these types of springs are rare and most undisturbed springs are in the process of recovering from past disturbances.

  Slightly Disturbed springs exhibit little evidence that vegetation or soil have been disturbed. Vegetation shows slight signs of browsing and foraging, and animal footprints and scat are present by not prominent. Recreation may be evident, but its impact on riparian or aquatic environments is minimal. Evidence of fire or flooding in the distant past may be visible but these events have occurred infrequently; riparian vegetation is vigorous.

  Moderately Disturbed springs exhibit evidence of recent, comparatively high levels of disturbance. In grazed systems, >50% of springbrook banks are covered by vegetation. Use by native and non-native ungulates, and recreation has reduced vegetation height and coverage compared to height under natural conditions. Where there has been diversion, a spring box may be present but ≥50% of natural discharge remains within the natural springbrook. Neither the spring nor springbrook has been impounded. Where flooding or fire are apparent, >50% of the springbrook banks are covered by vegetation; flood and fire are infrequent and the spring is naturalizing.

  Highly Disturbed springs have little similarity to undisturbed springs. Less than 50% of their banks are covered by vegetation, their springbrooks contain <50% of natural discharge, they are impounded or dredged, or spring boxes collect water. All impounded springs are highly disturbed because flow has been interrupted and functional characteristics of the aquatic system have been highly altered. Where ungulate use is heavy, hoof prints, trampled vegetation, scat, and sometimes pedestals can be common. Campsites can be conspicuous and littered, vehicle use evident. These activities can decrease vegetative cover to <50%,a dn high levels of non-native plant cover also often indicate disturbance. Some springs are naturally ephemeral, and such springs rarely if ever support springsnails; however distinguishing natural from anthopogenically dewatered springs requires monitoring. Ephemeral springs can be identified by the presence of upland riparian vegetation and absence of obligatory wetland plants. Riparian vegetation is sparse at springs recently affected by fire or flooding, there is recent evidence of elevated discharge, and springbrooks are usually incised.

- ****Identify*** current, imminent, or predicted threats to the persistence of springsnails and/or spring health.
- ****Notes***, to include additional pertinent information. This may include observations further describing site condition, use of the spring by other animals (e.g., bats, wild horses, etc.), clarification of difficulties in accessing the spring, etc.
- ****Sketch***, the spring by either marking on aerial photographs or creating a drawing. Document major spring sources (with identification labels) and features such as roads, fences, diversions, ditches, etc. Graph paper is provided above – make sure to indicate the scale of the squares (e.g., 1 cell = 1 m^2).

APPENDIX C: CROSSWALK OF STATE AND AGENCY RISK FACTOR DEFINITIONS

(Provided Electronically in Excel Format)

APPENDIX D: AGENCY RESPONSIBILITIES AND TASK PRIORITIZATION, CONSERVATION MEASURES AND BENEFITS, MEASURES OF SUCCESS, AND REPORTING SCHEDULE

(Provided Electronically in Excel Format)

APPENDIX E: SPRINGSNAIL POPULATION STATE DISTRIBUTION, INFORMATION QUALITY ANALYSIS, AND CALCULATOR FOR LOCAL AND FAR-FIELD HABITAT RISK ASSESSMENT AND STEWARDSHIP PRIORITIZATION

(Provided Electronically in Excel Format)

APPENDIX F: ELECTRONIC BIBLIOGRAPHY OF SCIENTIFIC SPRINGSNAIL LITERATURE

(Provided Electronically in Excel Format)

APPENDIX G: SPRINGSNAIL CONSERVATION PROJECTS AND DECISIONS IN NEVADA AND UTAH

(Compilation by the SCT Pending)