Environmental Characteristics of Great Basin and Mojave Desert Spring Systems

Donald W. Sada

Alexandra D. Lutz

Division of Hydrologic Sciences

August 12, 2016

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Environmental conditions recorded at 2,256 Great Basin and Mojave Desert springs that were inventoried from the late 1980s into 2013 are summarized. These records provide information about individual springs and their spatial variability across the landscape. Insight into their changing condition is provided by records compiled at springs visited several times over more than 20 years. Although this summary considers a small proportion of springs in this region, it provides broad insight into their size, basic water chemistry, and conditions that are indicative of springs over a large portion of the southwestern US.

This assessment examines physicochemical characteristics of all of the springs surveyed, and by segregating them by land manager or owner (e.g., U.S. Bureau of Land Management, U.S. Forest Service, U.S. Fish and Wildlife Service, and private). Springs ranged widely in size, water chemistry, vegetative cover, and substrate composition. Some springs were very large, as indicated by discharge, springbrook length, water depth, and wetted width. However, median estimated discharged from all springs was less than 10 l/min, springbrook length was less than 50 m, water depth was less than 3 cm, and median springbrook width was less than 100 cm. There was also a wide diversity in water chemistry, from cold to very hot springs, from low to very high electrical conductance (EC), moderately low to moderately high pH, and low to very high dissolved oxygen (DO) concentrations. Most were relatively moderate environments, however. Median temperature was near ambient, EC was relatively high, pH was slightly higher than neutral, and DO was moderate. Emergent and bank cover generally exceeded 50 and 68 percent, respectively, and fines dominated substrate composition in most springs. Sand, gravel, cobbles, and boulders were relatively scarce.

Approximately 3 percent the springs were disturbed by natural factors, and evidence of human disturbance was at approximately 83 percent of springs. Approximately 65 percent were moderately or highly disturbed by either diversion, horse, burro, or cattle use, recreation, or dredging, and many springs were degraded by several of these uses. Recent studies by Keleher and Radar (2008) and Sada et al. (2015) show that these levels of disturbance represent highly degraded, unhealthy ecosystems. Moderately or highly degraded springs were most common on Bureau of Land Management land, followed by private lands, U.S. Forest Service, and finally U.S. Fish and Wildlife Service lands.

Changes in the condition of 265 springs that were surveyed several times over 20 years found that condition improved in 16 percent of springs, were unchanged in 40 percent, but degraded in 44 percent of springs. Many Great Basin and Mojave Desert springs are occupied by rare aquatic life that occurs only in this region. Further evidence of degrading condition is exhibited by extirpation of 27 populations of these taxa between the late 1980s into 2013. Two extinctions were also documented over this period. All of this information shows that springs in this region are degraded, that degradation is continuing, and that current management is not providing for their ecological health.

Springs provide much of the aquatic environment in arid lands as well as a substantial portion of regional aquatic and riparian biodiversity, and water for rural economies. Springs were also highly symbolic and sacred places for Native Americans who believed that landscapes and homelands are often more important than events and time. New strategies are needed to manage and restore these systems, improve ecological health, and stop the extirpation of rare aquatic life that occurs only in Great Basin and Mojave Desert springs.

CONTENTS

EXECUTIVE SUMMARY iii
LIST OF FIGURES v
LIST OF TABLES vi
LIST OF ACRONYMS vii
INTRODUCTION 1
AREA DESCRIPTION 3
METHODS 5
RESULTS 7
    Physicochemical Characteristics 7
        All Springs 7
        Springs by Land Management 8
    Condition Due to Natural and Human Factors 12
    Temporal Changes in Spring Condition 15
    Decline and Extirpation of Aquatic Crenophiles 15
DISCUSSION 16
RECOMMENDATIONS 23
ACKNOWLEDGEMENTS 24
REFERENCES 25
Appendix A: GLOSSARY A-1
APPENDIX B: DATABASE ELEMENTS B-1
APPENDIX C: PHOTOGTRAPHS OF REPRESENTIVE SPRINGS WITH DIFFERENT DISTURBANCE LEVELS C-1

LIST OF FIGURES

1. Location and approximate boundaries of the Great Basin and Mojave Desert. 4
2. Location of Great Basin and Mojave Desert springs surveyed from the late-1980s into 2013 7

LIST OF TABLES

1. Spring survey elements (and units of measure) recorded for individual springs surveyed from the mid-1980s to 2013.. 6

2. Physicochemical characteristics of Great Basin and Mojave Desert arid land springs sampled from the late1980s into 2013. 8

3. Physicochemical characteristics of Great Basin and Mojave Desert arid land springs sampled from the late1980s into 2013 that are managed by the U.S. Bureau of Land Management and U.S. Forest Service. 10

4. Physicochemical characteristics of Great Basin and Mojave Desert arid land springs sampled from the late1980s into 2013 that are managed by the U.S. Fish and Wildlife Service and privately owned. 11

5. The proportion of rheocrenes, helocrenes, limnocrenes, and dry springs in the total dataset and the proportion on lands managed by federal agencies and privately owned. ... 12

6. The proportion of springs sampled from the late 1980s to mid-2013 that were categorized as undisturbed, or slightly, moderately, or highly disturbed by natural and human factors (N = 2213). 13

7. The number and proportion of surveyed springs that were undisturbed, and either moderately or highly disturbed by one, two, three, or four factors.. 13

8. The proportion of springs under different land management and ownership that were undisturbed, slight, moderate, and highly disturbed by natural and human factors.. 14

9. Changes in condition of springs recorded during several visits between the late 1980s into 2013. 15

10. The number of springs and taxa where severe declines, extirpations and extinctions were observed before the 1980s and between the mid-1980s into 2013. 16

11. Historical severe declines, extirpations, and extinctions recorded in Great Basin and Mojave Desert crenophiles. 17

12. The number of springs in Chihuahuan Desert and Mojave Desert Networks of National Parks surveyed during 2007- 2011.. 22

LIST OF ACRONYMS

BIBE	Big Bend National Park
BLM	U.S. Bureau of Land Management
BMI	Benthic Macroinvertebrate
CAVE	Carlsbad Caverns National Park
CHDN	Chihuahuan Desert
DEVA	Death Valley National Park
DO	Dissolved Oxygen
EC	Electrical Conductance
GPS	Global Positioning System
GUMO	Guadalupe Mountains National Park
JOTR	Joshua Tree National Park
LADWP	City of Los Angeles Department of Water and Power
LAME	Lake Mead National Recreation Area
MOJN	Mojave National Preserve
NPS	U.S. National Park Service
PARA	Grand Canyon-Parashant National Monument
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
WHSA	White Sands National Monument

THIS PAGE INTENTIONALLY LEFT BLANK

INTRODUCTION

Springs are small aquatic systems that occur where groundwater reaches the surface (Meinzer 1923). In deserts, they range widely in size, water chemistry, morphology, landscape setting, and persistence. Some springs dry each year, some dry only during extended droughts, while some persist for millennia. Desert springs are distinct from springs in more temperate or humid regions because they are typically isolated from other waters, some are more susceptible to drought, and aquifers in these regions are strongly influenced by high elevations, rugged topography, diverse lithology, and aridity (Thomas et al. 1996, Hershey et al. 2010). Geology, aquifer size, geography, climate, persistence of water, and the flow path of groundwater movement constitute the hydrologic context for each spring. These factors also provide the fundamental natural elements that influence spring environments and structure biotic communities. Sada and Thomas (draft manuscript) examined hydrogeology and ecology of reference Great Basin and Mojave Desert springs and found that the characteristics of benthic macroinvertebrate (BMI) communities were associated with aquifer characteristics and groundwater flow pathways.

Springs provide much of the aquatic environment in arid lands as well as a substantial portion of regional aquatic and riparian biodiversity (Hubbs 1995, Anderson and Anderson 1995, Myers and Resh 1999). Springs are also highly symbolic and sacred places for Native Americans who believe that landscapes and homelands are often more important than events and time (Fowler 2002, Livingston 2002). As a consequence of their lengthy isolation and long-term persistence, many Great Basin and Mojave Desert springs also support a crenophilic (obligate spring dwelling) and endemic fauna and flora (e.g., Sada 1990, Erman and Erman 1995, Hershler 1998, Baldinger et al. 2000, Polhemus and Polhemus 2002, Keleher and Sada 2012). When they are persistent, and unaffected by human activity, springs are generally more stable than lotic systems because they are not exposed to variability in temperature, discharge, and water chemistry (McCabe 1998). Variability in population size and assemblage structure of aquatic life in persistent springs is low compared to other aquatic systems, and springs are often occupied by animals unable to survive highly variable environments (van der Kamp 1995).

Ecological studies of arid land springs in the western U.S. have lagged behind studies of other aquatic systems, and restoration and management programs are in their infancy (Sada et al. 2001, Stevens and Merkesy 2008). In the USA, most studies have focused on crenophile taxonomy and biogeography (e.g., Miller 1948, Hershler 1998, Smith et al. 2002), physiological adaptations to extreme environments (e.g., Feldmeth et al. 1974, Schrode and Gerking 1977, O'Brien and Blinn 1999), autecology of individual, or groups, of closely related taxa (e.g., Forrester 1991, Sada 2007), ecological characteristics of individual springs or springs supported by a single aquifer (e.g., Weigert and Mitchell 1973, Meffe and Marsh 1983, Erman 1992, Blinn 2008), and colonization/extinction dynamics (Myers et al. 2001, Keheler and Rader 2008a). Many authors have noted the degraded condition of desert springs caused by diversion, non-native ungulate use, excessive groundwater pumping, non-native aquatic species, etc. (e.g., Shepard 1993, Sada et al. 2001, Unmack and Minckley 2008). Effects of these activities have been reported mostly as extirpations, extinctions, or declines in abundance of crenophiles (e.g., Miller 1961, Williams et al. 1985, Minckley and Deacon 1968, Sada and Vinyard 2002, Abele 2011). Historical records of extirpations and extinctions are recorded in historical literature, but these records have not been revised since Sada and Vinyard (2002).

Several studies provide insight into the ecological effects of disturbance on springs. Sada et al. (2005) and Fleishman et al. (2006) found that BMI and riparian communities in 63 Mojave Desert and southern Great Basin springs generally differed along an environmental stress gradient where highly disturbed springs supported depauperate communities composed of animals and plants that are more tolerant of harsh physicochemical environments than less disturbed springs. Statistically significant differences could not be detected between BMI and riparian communities in undisturbed and slightly disturbed springs, but differences between springs with these levels of disturbance significantly differed from communities in springs that were moderately or highly disturbed (Sada and Nachlinger 1998). In Colorado Plateau springs, Weissinger et al. (2012) examined disturbance and biological and hydrological characteristics of springs impacted by livestock and vehicle use and found that taxonomic richness was highest in moderately disturbed sites and that non-insect taxa richness was reduced in highly disturbed springs. They also observed that disturbance had no effect on nutrients, dissolved oxygen, pH, electrical conductance (EC), discharge, or substrate. Keleher and Radar (2008b) conducted a bioassessment analysis of 125 Bonneville Basin springs and categorized reference, moderately and, severely disturbed springs. They found that taxonomic richness was highest in severely disturbed springs, dipterans increased with disturbance, and they calculated metric scores for each class of spring.

Sada et al. (2015) examined 115 Nevada springs to assess the influence of natural and human disturbances and other physicochemical metrics on the BMI communities. They found that their structure was less affected by natural factors (e.g., water temperature, elevation, electrical conductance, etc.) than they were to the level of disturbance that was qualitatively categorized as undisturbed, slightly, moderately, or highly disturbed by avalanches, fire, floods, drying, livestock, horses or burros, diversion, dredging, or recreation. Disturbance level was also correlated with the concentration of most nutrients, but water temperature and chloride concentration were the only statistically significant chemical variables. Stoichiometric analysis indicated that gastropod food quality was negatively affected in springs associated with non-native ungulate use. Bioassessment metrics showed that functional characteristics of moderately and highly disturbed springs were characterized by assemblages and taxa that are more tolerant of harsh or polluted conditions than taxa occupying un- or slightly disturbed springs. Examination of highly disturbed springs found that differences between natural and human disturbances were not statistically significant.

This report summarizes environmental conditions recorded at 2,256 Great Basin and Mojave Desert springs that were inventoried from the late 1980s into 2013. These records provide information about individual springs and their spatial variability across the landscape, and insight into their changing condition is provided by records compiled at springs visited several times over 20 years. Although this summary considers a small proportion of springs in this region, it provides broad insight into their size, basic water chemistry, and conditions that are indicative of springs over a large portion of the southwestern US.

AREA DESCRIPTION

Great Basin and Mojave Deserts lie in the Basin and Range Province of North American and encompass more than 25 percent of the United States (Figure 1). The area

Figure 1. Location and approximate boundaries of the Great Basin and Mojave Desert.

extends from southern California and northern Arizona to southern Oregon and Idaho, and westward from central Utah to eastern California (Darlington 1996, Grayson 2011). Annual precipitation is greater than 75 cm in mountains and less than 5 cm in some valleys. The Great Basin includes more than 30 mountains that exceed 3,050 m elevation, and its valley floors range in elevation from below sea level in to higher than 2,100 m. Boundaries of the Great Basin vary among physiographers, botanists, ethnographers, and hydrologists. For this study, it is defined by its hydrology, as a series of more than 150 north-south oriented mountain ranges that drain internally and into isolated valleys (endorehic basins) that haven't connected to drainages flowing to the ocean in recent times. This area covers approximately 492,000 km^2.

The Mojave Desert includes approximately 117,000 km^2 of southern California, Nevada and northwestern Arizona and it is the hottest and most arid area in the US, with summer temperatures exceeding 55ºC (Darlington 1996, Pavlik 2008). Its boundaries are defined by its vegetation, and mostly the presence of yucca trees (*Yucca brevifolia*). Due to similar vegetative characteristics, the two areas overlap and approximately 10 percent of the Great Basin is included in the Mojave Desert and approximately 40 percent of the Mojave Desert lies with the hydrographic Great Basin (Figure 1). Most Mojave Desert valley floors are lower elevation than northern Great Basin valleys.

Geology of this region is varied. Some mountain ranges are basaltic (volcanic), and others are limestone or granite. All of them receive winter snow, which acts as a reservoir that recharges groundwater during runoff. Valleys are filled with alluvium. The region is sparsely populated by rural communities and isolated ranches. The largest cities are Salt Lake City, Utah and Las Vegas, Nevada.

METHODS

Springs were surveyed from the late1980s into 2013. Survey protocols changed slightly over this period to include additional factors, but each survey included a base of information describing spring source location, basic water chemistry, physical habitat characteristics (including the cause and level of disturbance), and the presence of important animals (Table 1, see Appendix A for a glossary of terms and Appendix B for a description of survey elements). Attempts were made to collect all of this information during each survey, but each element was not recorded during some surveys due to equipment malfunction or neglect. Measuring dissolved oxygen and pH was discontinued in later surveys because these metrics change many times throughout the day and night (due to photosynthesis and temperature) and single measurements may provide misleading or erroneous information. Water chemistry was measured as close to a spring source as possible, and habitat metrics were estimated in the upper 25 m of springbrook.

Table 1. Spring survey elements (and units of measure) recorded for individual springs surveyed from the late1980s into 2013. Appendix A is a glossary of terms, and descriptions of collection methods for each element are in Appendix B.

Spring ID No.	**pH**
Field Note No.	Estimated Discharge (Liters/minute)
Surveyor	Estimated Springbrook Length (meters)
Survey Date	Estimated Average Water Depth (cm)
State	Estimated Average Wetted Width (cm)
County	Estimated Bank Cover (%)
Spring Name	Estimated Emergent Cover (%)
Drainage Basin	Estimated Substrate Composition (%)
Township, Range, & Quarter Section	Presence of Non-Native Species
GPS Coordinates	Presence of Springsnails
100,000 USGS Topo Name	Presence of Amphibians
Landowner/Manager	Presence of Fish
Elevation (meters)	Presence of Amphipods
Spring Morphology	Presence of clams
Water Temperature (^{o}C)	Presence of Important Vegetation
Electrical Conductance (µmhos/second)	Site Condition (Disturbance Cause & Rating)
Dissolved Oxygen Concentration (mg/l)	Notes

Most early surveys (through the 1990s) were conducted during springsnail taxonomy and distribution studies, and most subsequent surveys were a component of studies to identify and quantify habitats required by crenophiles or the effects of human and natural disturbance on spring ecology. Most springs were located on valley floors and bajadas, but a number were also in mountains. Springs were selected from 1:100,000 scale USGS topographic maps for most early surveys in Nevada, and many subsequent surveys included all springs within a study area. Most springs in Utah were selected *a priori* for the presence of springsnails. Springs were typically visited once, but many were also visited several times, which provides information to assess temporal trends in condition. These surveys included an unknown portion of springs in the region, but the large number of springs studied provides insight into characteristics of springs throughout the region. Changes in condition observed during several visits also indicates how current and past uses are affecting springs over time.

RESULTS

A total of 2,644 records for 2,256 springs were compiled from the late-1980s into 2013. These springs were either currently or historically occupied by 145 crenophiles and native fish (gastropods, insects, crustaceans), and inhabited by 12 non-native species. Springs were widely distributed throughout the region and ranged in elevation from below sea level in Death Valley to almost 3,100 m in the Spring Mountains of southern Nevada (Figure 2, Table 2).

PHYSICOCHEMICAL CHARACTERISTICS

All Springs

Mean elevation was relatively high (1622 m), due to the high elevation of most valleys, but most were below 1,505 m (Table 2). Springs ranged widely in size, water chemistry, vegetative cover, and substrate composition. Some springs were very large, as

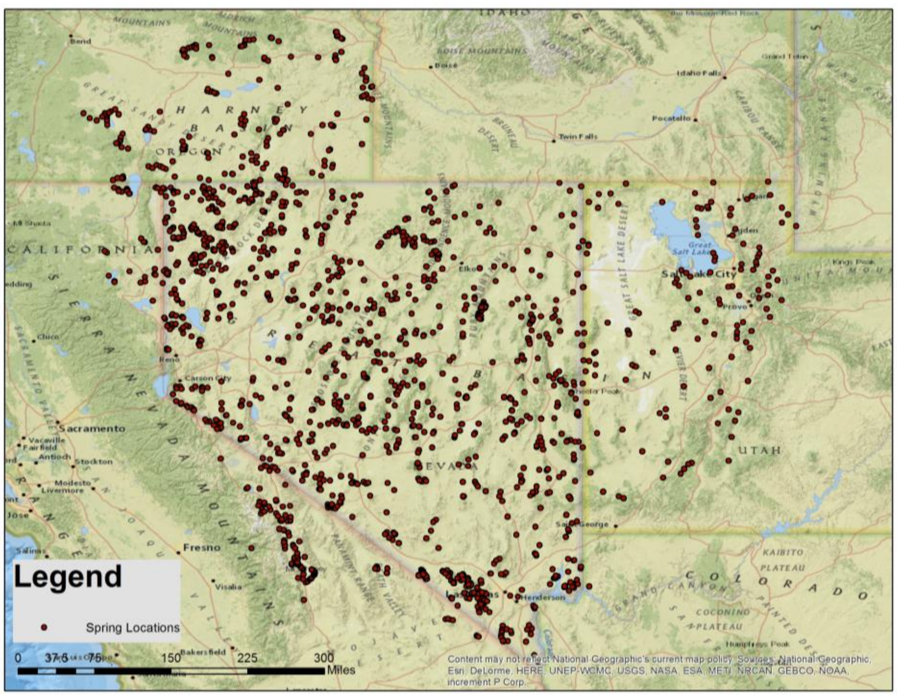

Figure 2. Location of Great Basin and Mojave Desert springs surveyed from the late1980s into 2013.

Table 2. Physicochemical characteristics of Great Basin and Mojave Desert arid land springs sampled from the late1980s into 2013. N = the number of springs examined for each metric.

Metric	N	Mean	Median	Min	Max
Elevation (m)	2198	1505	1622	-85	3097
Discharge (l/min)	826	189	10	0	33980
Springbrook Length (m)	718	633	50	0	8000
Water Depth (cm)	1781	31.3	3	3	30000
Wetted Width (cm)	1770	460	100	0	2000
Temperature (^oC)	1698	18.4	16.3	3.3	107
Electrical Conductance (µmhos/sec)	1608	727	391	2.6	58700
pH	1465	7.8	7.7	4.0	9.9
Dissolved Oxygen (mg/l)	1203	6.2	6.2	0.1	22.7
% Emergent Cover	1816	53	60	0	100
% Bank Cover	1804	68	80	0	100
% Fines	1772	57	65	0	100
% Sand	1609	20	10	0	100
% Gravel	1648	23	10	0	100
% Cobble	1568	8	0	0	100
% Boulder	1544	1	0	0	80

indicated by discharge, springbrook length, water depth, and wetted width. However, one-half of springs discharged less than 10 l/min, median springbrook length was less than 50 m, water depth was less than 3 cm, and median springbrook width was less than 100 cm (Table 2). There was also a wide diversity of water chemistries, from cold to very hot, from low to very high EC, moderately low to moderately high pH, and low to very high DO (Table 2). A number of geothermal springs were surveyed (with harsh environments), but most environments were relatively moderate. Median temperature was near ambient, EC was relatively high, pH was slightly higher than neutral, and DO was moderate. Emergent and bank cover generally exceeded 50 and 68 percent, respectively, and fines dominated substrate composition in most springs (Table 2). Sand, gravel, cobbles, and boulders were relatively scarce (Table 2).

Springs by Land Management

Records include springs managed by the U.S. Bureau of Land Management (BLM), U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (USFWS), U.S. National Park

Service (NPS), and privately owned. U.S. Fish and Wildlife Service included all springs on Ash Meadows, Ruby Lake (RL), and Moapa National Wildlife Refuges (NWR) in Nevada, and some springs on Fish Springs NWR, Utah. Springs on NPS lands included some on Lake Mead National Recreation Area (LAME), Nevada, and Death Valley (DEVA) National Park, California. A number of springs were located on State, Tribal, etc. lands. Ownership/management of these springs is referred to as miscellaneous (MSC). The following discussion will not include springs on NPS lands because records in the DRI database represent a small portion of these springs, and are therefore not representative of springs in these parks. Refer to work by Sada and Pohlmann (2007), Sada et al. (2000), and Sada and Jacobs (2008) for summaries of surveys that included all DEVA, LAME, and RLNWR springs.

Environmental characteristics generally followed a pattern relative to landscape associations, management, and ownership (Tables 3 & 4). Median elevation of USFS springs was higher than other managers and owners, due to their location on mountains. Mean elevation of BLM and private springs were similar due to their primary location on valley floors, and USFWS were the lowest, which is due to the large number of springs sampled on Ash Meadows and Moapa NWRs (~ 700 m elevation). BLM and USFS springs were both small. Median estimated discharge was 4 l/min and water depth was 2 cm. BLM springbrooks were wider (median = 100 cm) that USFS (median = 75 cm), but USFS springbrooks were generally longer than those on BLM (100 m vs. 40 m, respectively). Springs on private land were slightly larger than on either BLM or USFS. Their median discharge was 13 l/min, water depth 3 cm, wetted width 120 cm, and median springbrook length was 60 m. USFWS springs were the largest, which is due to the inclusion of large, high quality springs on lands managed by this agency.

Median water temperature and EC were the lowest on USFS land, which is consistent with their elevation and their support by mountain aquifers (Tables 3 & 4). Median temperature of BLM and private springs were similar, but the EC of BLM springs were slightly higher.

Table 3. Physicochemical characteristics of Great Basin and Mojave Desert arid land springs sampled from the late1980s into 2013 that are managed by the U.S. Bureau of Land Management (BLM) and U.S. Forest Service (USFS).

	BLM				USFS			
Metric	**N**	**Median**	**Min**	**Max**	**N**	**Median**	**Min**	**Max**
Elevation (m)	720	1615	256	2353	187	1859	468	3097
Discharge (l/min)	308	4	0	4020	80	4	0	1000
Springbrook Length (m)	260	40	0	5000	59	100	0	2000
Water Depth (cm)	576	2	0	150	176	2	0	100
Wetted Width (cm)	571	100	0	20000	172	75	0	5000
Temperature (^{o}C)	547	16.8	5.2	85.0	154	13.1	3.3	35.0
Electrical Conductance (µmhos/sec)	520	439	4	9720	147	320	25	1285
pH	461	7.7	6.3	9.9	152	7.9	4.0	9.0
Dissolved Oxygen (mg/l)	381	6.2	0.4	22.7	138	6.3	0.5	13.2
% Emergent Cover	574	60	0	100	171	25	0	100
% Bank Cover	572	70	0	100	169	90	0	100
% Fines	568	70	0	100	165	20	0	100
% Sand	538	10	0	100	163	5	0	100
% Gravel	536	0	0	100	165	20	0	100
% Cobble	524	0	0	100	164	0	0	100
% Boulder	520	0	0	50	163	0	0	40

Many USFWS springs discharge from a regional aquifer, which is why these springs were generally warmer with ECs greater than springs on other lands. Median DO concentrations and pH were similar on all lands, and within the range of healthy aquatic systems. Since both of these change nocturnally, these daytime readings may poorly indicate the health of these systems due to nighttime conditions that may differ widely from daytime. This information can only be provided by diurnal studies to determine the range temporal variability in DO and pH.

The median proportion of springbrook banks covered by vegetation was highest in privately owned and USFS springs, but it was 70 percent or greater in all other springs

(Tables 3 & 4). Emergent vegetation was lowest in USFS springs, which may be attributed to their high elevation and swift currents that are associated with steep slopes and springbrooks.

Table 4. Physicochemical characteristics of Great Basin and Mojave Desert arid land springs sampled from the late1980s into 2013 that are managed by the U.S. Fish and Wildlife Service (USFWS) and privately owned.

	USFWS				**Private**			
Metric	**N**	**Median**	**Min**	**Max**	**N**	**Median**	**Min**	**Max**
Elevation (m)	160	1271	411	2076	903	1646	259	2455
Discharge (l/min)	72	666	0	33980	295	13	0	4000
Springbrook Length (m)	66	319	0	5000	263	60	0	2000
Water Depth (cm)	141	38	0.5	30000	761	3	0	2200
Wetted Width (cm)	138	449	3	2000	762	120	0	5000
Temperature (°C)	143	20.7	5.0	107	728	16.1	4.0	17.0
Electrical Conductance (µmhos/sec)	140	684	9.5	3163	686	372	2.6	58700
pH	127	7.7	6.0	9.0	621	7.8	4.8	9.9
Dissolved Oxygen (mg/l)	123	5.2	0.8	12.1	478	6.4	0.1	21.3
% Emergent Cover	142	54	0	100	797	70	0	100
% Bank Cover	141	78	0	100	791	90	0	100
% Fines	119	63	0	100	744	72	0	100
% Sand	81	28	0	100	698	10	0	100
% Gravel	85	39	0	100	734	0	0	100
% Cobble	69	9	0	100	686	0	0	100
% Boulder	65	5	0	80	679	0	0	50

Fines dominated the substrate composition of BLM, private, and USFWS springs, but it was uncommon in USFS springs, which may also be attributed to greater slope and higher current velocities in mountain springs. Substrate composition included a greater diversity of sizes in private and USFWS. Cobble and boulder were uncommon in all springs, and dominated the substrate only in a few USFWS springs (Tables 3 & 4).

Rheocrenes were the most common springs, followed by helocrenes and limnocrenes (Table 5). Helocrenes were scarce on USFS lands, due to steep slopes and mountainous terrain where flat areas that are necessary for helocrenes are uncommon. Dry springs were most common on BLM land, due to their low elevation and drier climates.

Table 5. The proportion of rheocrenes, helocrenes, limnocrenes, and dry springs in the total dataset and the proportion on lands managed by federal agencies and privately owned.

Type	All Springs	BLM	USFS	USFWS	Private
Rheocrene	0.64	0.58	0.91	0.75	0.62
Helocrene	0.20	0.21	0.01	0.12	0.25
Limnocrene	0.09	0.05	0.0	0.13	0.08
Dry	0.06	0.11	0.08	0.10	0.04

Condition Due to Natural and Human Factors

The cause, and relative amount (undisturbed, slight, moderate, or high), of disturbance were categorized during surveys (see Appendix B for description of disturbance categories). Natural disturbance included avalanche, fire, flood, and natural drying, and evidence of diversion, horses and burros, cattle, and recreation were categorized as human disturbance. Photographs of representative springs exposed to different levels of disturbance are shown in Appendix C.

Relatively few of the springs were disturbed by natural factors, and cattle use and diversions (mostly for cattle use) were the most common human factors influencing condition (Table 6). Human use was evident at approximately 83 percent of springs, and 65 percent of springs were either moderately or highly disturbed by human uses (Table 7). Most springs had been disturbed by more than one activity (Table 7). Approximately 57 percent of springs were affected by a single type of disturbance, and 34 percent, 8 percent were altered by two or three factors, respectively. Six moderately or highly disturbed springs had been altered by four or more factors. The highest frequency of disturbance was observed on BLM land (73 percent), followed by private land (69 percent) the miscellaneous lands (military, state, etc. ownerships). The lowest frequency of disturbance was on lands managed by the USFWS.

Cattle and diversions were the most common disturbances on all lands (Table 8). Diversion and dredging were the most common disturbances on USFWS lands, due their active manipulation of springs to enhance waterfowl use.

Table 6. The proportion of springs sampled from the late 1980s into 2013 that were categorized as undisturbed, or slightly, moderately, or highly disturbed by natural and human factors (N = 2213).

Disturbance	Undisturbed	Slight	Moderate	High
Natural Factors				
Avalanche	0.99	0.0	0.0	0.0
Fire	0.99	0.0	0.0	0.0
Flood	0.97	0.01	0.0	0.0
Drying	0.96	0.0	0.0	0.03
Human Factors				
Diversion	0.64	0.04	0.08	0.24
Horses/Burros	0.92	0.02	0.03	0.03
Cattle	0.44	0.12	0.19	0.26
Recreation	0.86	0.06	0.04	0.05
Dredging	0.94	0.01	0.0	0.03

Table 7. The number and proportion of surveyed springs that were undisturbed, and either moderately or highly disturbed by one, two, three, or four factors (factors listed in Table 6). Compiled for all springs surveyed and springs segregated by land managers or ownership. N = number of springs surveyed, BLM = U.S. Bureau of Land Management, USFS = U.S. Forest Service, USFWS = U.S. Fish and Wildlife Service, NPS = National Park Service, MSC = springs with undetermined ownership or on land owned by states, tribes, the military, etc. Springs that were affected by four or more factors (N = 5) not included in the table.

Ownership	Total N Surveyed	Undisturbed	Slight	Moderate or High	One	Two	Three
All Springs	2213	0.18	0.17	0.65	0.57	0.34	0.08
BLM	741	0.06	0.21	0.73	0.49	0.39	0.11
USFS	208	0.21	0.26	0.53	0.63	0.32	0.05
USFWS	162	0.36	0.20	0.44	0.63	0.35	0.01
Private	916	0.12	0.21	0.69	0.62	0.30	0.08
MSC	67	0.13	0.22	0.65	0.60	0.34	0.04

Table 8. The proportion of springs under different land management and ownership that were undisturbed, slight, moderate, and highly disturbed by natural and human factors. Proportions rounded to the nearest 0.005 and * denotes disturbances that were noted but the occurrence was less than 0.05., and H/B is horse/burro disturbance.

	Avalanche	Fire	Flood	Drying	Diversion	H/B	Cattle	Recreation	Dredging
BLM									
Undisturbed	1.0	1.0*	0.95	0.94	0.56	0.88	0.35	0.87	0.96
Slight	0.0	0.0	0.02	0.0	0.04	0.02	0.10	0.04	0.01
Moderate	0.0	0.0	0.01	0.0	0.06	0.03	0.17	0.03	0.01
Highly	0.0	0.0	0.01	0.06	0.33	0.05	0.37	0.05	0.02
USFS									
Undisturbed	1.0*	1.0	0.93	**0.93**	0.62	0.87	0.55	0.84	0.96
Slight	0.0	0.0	0.01	0.0	0.05	0.03	0.11	0.10	0.0
Moderate	0.0	0.0	0.02	0.0	0.06	0.07	0.15	0.01	0.0
Highly	0.0	0.0	0.01	0.0	0.24	0.03	0.15	0.0	0.0
USFWS									
Undisturbed	1.0	1.0*	0.95	0.95	0.66	**0.88**	**0.70**	0.90	0.73
Slight	0.0	0.0	0.01	0.01	0.04	0.01	0.12	0.02	0.04
Moderate	0.0	0.0	0.0	0.0	0.10	0.02	0.07	0.02	0.04
Highly	0.0	0.0	0.0	0.0	0.15	0.04	0.06	0.01	0.10
Private									
Undisturbed	1.0	1.0*	0.96	0.94	**0.65**	0.92	0.35	0.80	0.91
Slight	0.0	0.0	0.0	0.0	0.03	0.01	0.13	0.06	0.01
Moderate	0.0	0.0	0.0	0.0	0.09	0.02	0.24	0.04	0.02
Highly	0.0	0.0	0.0	0.03	0.20	0.02	0.26	0.06	0.03
MSC									
Undisturbed	1.0	1.0	1.0	0.96	0.56	0.93	0.44	0.82	0.88
Slight	0.0	0.0	0.0	0.0	0.11	0.01	0.19	0.07	0.03
Moderate	0.0	0.0	0.0	0.01	0.13	0.01	0.19	0.07	0.06
Highly	0.0	0.0	0.0	0.02	0.24	0.04	0.16	0.04	0.02

Relatively few springs had evidence of horses or burros, which could be attributed to their more common occurrence in the northern Great Basin. Wild horse management programs began reducing these invasive animals in the late 1971, but their abundance is increasing and evidence of their focused use of springs is common where they occur.

TEMPORAL CHANGES IN SPRING CONDITION

A total of 265 springs were visited at least two times from the late1980s into 2013. Assessment of changes in their condition were evaluated by determining the worst condition observed for each spring during the first and later surveys (Table 9). The condition of springs trended toward increasing degradation over time with the number of undisturbed springs decreasing and the number of highly disturbed springs increasing. Conditions were unchanged in approximately 40 percent of these springs, improved in 16 percent, and conditions degraded in approximately 44 percent of springs.

DECLINE AND EXTIRPATION OF AQUATIC CRENOPHILES

Sada and Vinyard (2002) compiled extinction and decline records for 199 endemic Great Basin aquatic taxa occupying lakes, streams, and springs. They documented 16 extinctions, and for taxa where there were records (135 taxa), they reported population losses for approximately 50 percent of taxa, and 58 percent of these taxa had undergone severe declines (loss > 50 percent of abundance or distribution). Declines were attributed to habitat alteration or introduction of non- native invasive species, and they were reported only if status changes were documented by numerous surveys. Quantifying extinction and absolute extirpation of populations is challenging. Crenophilic BMIs are small and often difficult to locate when populations are small, and extirpation and can only be verified by numerous surveys. However, extirpations and extinctions are always associated with habitat alterations (diversion, excessive non-native ungulate use, etc.), or the previously unrecorded presence of non-native species

Table 9. Changes in condition of springs recorded during several visits between the late 1980s into 2013. Shown as the proportion of springs whose worst condition was recorded during the earliest and later surveys were evaluated as undisturbed, slightly, moderately, and highly disturbed.

	Undisturbed	Slight	Moderate	High
Worst, Early	0.15	0.19	0.31	0.35
Worst, Late	0.09	0.19	0.31	0.49

The abundance and distribution of Great Basin and Mojave Desert crenophiles changed before and during surveys from the late1980s into 2013. Table 10 summarizes these changes, and the springs and taxa are shown in Table 11. Populations that were easily found during early surveys, but were either absent or exceedingly scarce during subsequent surveys were categorized as ‘Severe’ declines. Populations not located during several surveys were categorized as ‘Extirpated’, and extinctions are taxonomic extirpations. Severe declines were observed in relatively few springs. The number of springs where extirpations were recorded from the mid-1980s into 2013 was twice the number recorded before the 1980s, but the number of taxa was similar over the two periods. A single extinction, a taxon occupying a single spring, was recorded from the 1980s into 2013, 10 extinct taxa occupying seven springs were documented before the 1980s.

DISCUSSION

Springs are distinguished steady-state systems that are minimally influenced by environmental variability. Their broad importance to science was recognized when basic elements of ecology and energy flow were formulated by Forbes (1887), Elton (1927), and Lindeman (1942), and quantified by Odum (1957 a, b) in Silver Springs, Florida. They have continued to capture the imagination of scientists and recent studies have focused springs in mesic regions and natural factors affecting communities, assemblages, and individual taxa (e.g., Williams and Danks 1999, Botosaneau 1998, Ferrington 1995). Interest in arid land springs is

Table 10. The number of springs and taxa where severe declines, extirpations and extinctions were observed before the 1980s and between the late1980s into 2013. See Table 11 for a list of springs and taxa.

Declines	No. Springs	No. Taxa
1980s-2013 Severe	7	6
1980s-2013 Extirpated	23	27
Pre-1980s Extirpated	12	23
1980s-2013 Extinction	1	2
Pre-1980s Extinction	7	10

Table 11. Historical severe declines, extirpations, and extinctions recorded in Great Basin and Mojave Desert crenophiles. Severe declines defined as sites where populations were not located during one or more surveys, but extirpation is uncertain or the population was rediscovered after long apparent absence. Extirpations were populations that could not be documented following several surveys. These taxa are extant in other springs. *P. = Pyrgulopsis, T. = Tryonia, R. o. = Rhinichthys osculus, S = Siphateles*.

Spring	Taxa(on)	Decline	Decade	Cause
Blue Pt. Sp., NV	*P. coloradensis,* *T. infernalis*	Severe	1990	Non-native aquatic species
Horseshutem Sp., NV	*P. turbatrix*	Severe	2010s	Ungulate use, Diversion
Coyote Sp., NV	*P. aurata*	Severe	1990s	Ungulate use
Buffalo Sp., NV	*P. sadai*	Severe	2000s	Diversion, Ungulate Use
Clay Pits Sp., NV	*P. licina*	Severe	1990s	Drying
S. of Clay Pits, Sp., NV	*P. licina, T. variegata*	Severe	2000s	Drying
Willow Sp., NV*	*P. deaconi, P. turbatrix*	Extirpated	1970s	Diversion
Grapevine Sp., NV	*P. turbatrix*	Extirpated	1990s	Diversion
Dolly Varden, Sp., NV	*P. cruciglans*	Extirpated	2000s	Diversion
Dyer Ranch Sp., NV	*P. wongi*	Extirpated	1990s	Groundwater pumping
Fish Lake Valley, Sp., NV	*S. bicolor*	Extirpated	1990s	Non-native aquatic species
Maiden Sp., NV	*P. sadai*	Extirpated	2010s	Diversion, Ungulate Use
Revert Sp., NV	*P. micrococcus*	Extirpated	1990s	Diversion
Fairbanks Sp., NV	*R. o. nevadensis*	Extirpated	1940s	Collection, Non-native species
Huntoon Sp., NV	*P. wongi*	Extirpated	1990s	Unknown
Jackrabbit Sp., NV	*P.* sp., *T.* sp.	Extirpated	1970s	Diversion
Longstreet Sp., NV	*R. o. nevadensis, P. sp.*	Extirpated	1940s	Pumping, Non-native aquatic species
Moapa Warm Spgs. NV (2)	*P. carinifera, P. avernalis, T. clathrata, Mi. moapensis, St. moapa, Mo. coriacea*	Extirpated	1990s	Diversion
Unnamed Sp., Steptoe Valley, NV	*P. serrata*	Extirpated	2000s	Ungulate Use
Hiko Sp., NV	*P. hubbsi*	Extirpated	2000s	Impoundment, Diversion

Table 11 (continued). Historical severe declines, extirpations, and extinctions recorded in Great Basin and Mojave Desert crenophiles. Severe declines defined as sites where populations were not located during one or more surveys, but extirpation uncertain or population reappeared after long apparent absence. Extirpations were populations that could not be documented following several surveys. These taxa are extant in other springs. *P. = Pyrgulopsis, T. = Tryonia, R. o. = Rhinichthys osculus. E. = Empetrichtys, C. = Cyprinodon, S. = Siphateles, A. = Ambrysus*, I. =*Ipnobius, M. = Microcylloepus, A. = Ambrysus, H. = Hyallela*.

Spring	Taxa(on)	Decline	Decade	Cause
Bradford Sp., NV	*P*. sp., *T*. sp.	Extirpated	1970s	Diversion
Travertine Sps. (3), CA	*I. robustus, H. sandra, H. muerta, Mi. formicoideus, A. funebris*	Extirpated	1930's	Diversion
Bradford Sp., NV	*P*. sp., *T*. sp.	Extirpated	1970s	Diversion
Tubbs Sp., NV	*P. sp., T. sp.*	Extirpated	1970s	Diversion
N. Scruggs Sp., NV	*P. ericae, P. pisteri, T. variegata*	Extirpated	1990s	Non-native aquatic species
S. Scruggs Sp., NV		Extirpated	1990s	Non-native aquatic species
School Sp., NV*	*P. pisteri, T. variegata*	Extirpated	1990s	Non-native aquatic species
N. Indian Sp., NV	*T. variegata*	Extirpated	1990s	Non-native aquatic species
Long Valley Warm Sp., CA	*R. o.*	Extirpated	1990s	Non-native aquatic species
Hot Creek Spgs., CA	*R. o.*	Extirpated	1950s	Habitat alteration, Non-native species
S. Indian Sp., NV	*T. variegata*	Extirpated	1990s	Non-native aquatic species
Manse Ranch Sp., NV	*E. latos latos*	Extirpated	1950s	Groundwater pumping
Long Valley Warm Sp., CA	*R. o.*	Extirpated	1990s	Non-native aquatic species
Hot Creek Spgs., CA	*R. o.*	Extirpated	1950s	Habitat alteration, Non-native species
Fish Slough Spgs., CA	*R. o.*	Extirpated	1950s	Non-native aquatic species
7 Mile Sps. (4), NV	*P. longiglans*	Extirpated	2000s	Ungulate use, Diversion
Lower Tassi Sp., AZ	*P. bacchus*	Extirpated	1930s(?)	Diversion
Little Lake Sps., CA	*R. o.*	Extirpated	1940s	Diversion, Impoundment, Non-native species

Table 11 (continued). Historical severe declines, extirpations, and extinctions recorded in Great Basin and Mojave Desert crenophiles. Severe declines defined as sites where a population was not located during one or more surveys, but extirpation uncertain or the population reappeared after long apparent absence. Extirpations were populations that could not be documented following several surveys. These taxa are extant in other springs. Parentheses shows the number of occupied springs. *P.* = *Pyrgulopsis*, *T.* = *Tryonia*, *R. o.* = *Rhinichthys osculus*. *E.* = *Empetrichtys*.

Spring	Taxa(on)	Decline	Decade	Cause
Fish Slough, CA	*R.o.*	Extirpated	1960s	Non-native aquatic species
Manse Sp., NV	*E. latos latos, P. deaconi*	Extirpated	1970s	Groundwater pumping
Silver Sp., NV	*P. marcida*	Extirpated	1990s	Ungulate use, Diversion
Ruppes Bog Hole Sp., NV	*P. marcida*	Extirpated	2000s	Ungulate Use
Antelope, North Sp., NV	*P. longiglans*	Extirpated	2010s	Diversion
Five Sps., NV	*T. variegata, P. nanus, P. sanchezi*	Extirpated	2000s	Non-native aquatic species
Rogers Sp., NV	*E. merriami* *R. o. nevadensis*	Extinct Extirpated	1940s	Collection, Non-native species
Crystal Pool, NV	*E. merriami* *R. o. nevadensis*	Extinct Extirpated	1940s	Collection, Non-native aquatic species
Big Sp., NV	*E. merriami* *R. o. nevadensis*	Extinct Extirpated	1940s	Collection, Non-native aquatic species
Forest Sp., NV	*E. merriami* *R. o. nevadensis*	Extinct Extirpated	1940s	Collection, Non-native aquatic species
High Rock Sp., CA	*S. bicolor*	Extinct	1990s	Non-native aquatic species
Raycraft Ranch Sp., NV	*E. latos concavus*	Extinct	1950s	Groundwater pumping
Pahrump Ranch Spgs., NV	*E. latos pahrump*	Extinct	1950s	Dredging, non-native aquatic species
Panaca Big Sp., NV	*Tryonia* sp.	Extinct	1940s	Impoundment, Diversion
McNett Ranch, Sp., NV	*P. ruinosa*	Extinct	1990s	Impoundment
Las Vegas Spgs., NV	*R. o. deaconi*	Extinct	1440s	Diversion, Groundwater pumping
Kings Pool, NV	*E. merriami*	Extinct	1940s	Collection, Non-native species

* = Springs and taxa where taxa were extirpated and subsequently reestablished.

is increasing (e.g., Sada et al. 2001, Sada and Sharpe 2002, Stevens and Meretksy 2008), but knowledge of their ecology and how to implement management that is compatible with maintaining ecological integrity is comparatively limited.

Great Basin and Mojave Desert springs are occupied by many species that occur in lakes, streams, and rivers throughout western North America. These species are highly vagile and able to readily move across the landscape from one habitat to the next. Their presence or absence from a spring is a function of environmental conditions, which usually varies in response to a variety of factors such as water chemistry and human and natural disturbances. Sada and Thomas (in review) described relationships between aquifer provenance, landscape setting, and water chemistry on BMI communities. They found statistically significant differences in the structure and functional characteristics of BMI communities in springs fed by mountain aquifers, regional aquifers, and local aquifers that fed geothermal, valley floor, bajada, and playa springs. Differences between these categories of springs shows that ecological characteristics differ between them, and that successful management cannot be determined by applying a single set of metrics for all springs. For instance, metrics that define the ecological health of mountain springs cannot be use to determine the health of valley floor springs.

The effects of disturbance on Great Basin and Mojave Desert spring systems are known from work by Keleher and Radar (2008) in the Bonneville Basin, and by Sada et al. (2015) in Nevada. Both studies found that benthic communities differed between disturbed and undisturbed springs, and that communities also changed along a gradient of increasing intensity of disturbance. Integrating insight provided by Sada and Thomas (in review) and these two studies provides guidance to set management and restoration goals, and to understand how spring systems will respond to conservation efforts.

Environmental variability among arid land springs exceeds that of springs in mesic regions due to the diversity of climates, geologies, and landscapes in desert regions. This difference is particularly expansive in the Great Basin and Mojave Desert, which encompass the most mountainous and driest region in North America. Springs in this region occur at high elevations (> 3000 m) to below sea level. Aquifers in the region flow through volcanics, sandstone, granite, and carbonate, where residence times range from less than one to thousands of years. Some springs are perched and cool, water for some circulates deeply and heats geothermally, many emerge through recently deposited alluvium, and some through ancient lakebeds. Most aquatic life in desert springs is widely distributed throughout North America, but many springs also support a large number of crenophilic, endemic vertebrates and invertebrates (Polhemus and Polhemus 2002, Sada and Vinayard 2002, Howard et al. 2015) that occur only in steady state, persistent systems where natural events (e.g., scouring floods, drying, etc.) do not cause shifts in ecosystem function. Recent studies show that some crenophiles have been isolated from ancestral forms for 0.5 ma, and some fish and springsnails have occupied spring systems since the late Miocene or early Pliocene (e.g., Smith et al. 2002, Wells et al. 2004, Hershler and Liu 2008, Echelle 2008). Recent extirpation and extinction of these taxa indicates that their habitats have undergone environmental change that is greater than what they have experienced for millennia.

Most Great Basin and Mojave Desert springs surveyed between the late 1980s into 2013 had been degraded by human activities, and evidence of natural events influencing their condition was uncommon. These results differ from observations in approximately 1,500 springs surveyed in many western US desert National Parks from 2007 to 2011 (Sada and Pohlmann 2007, Sada and Jacobs 2008, Sada 2013; Table 12). Human disturbance was evident at many of these springs, but natural disturbance (drying and scouring floods) was much more common, which is why crenophilic species do not occur in most of these National Parks. Differences between National Park springs and our Great Basin and Mojave Desert springs may be attributed the relative scarcity of mountain springs surveyed from the late 1980s into 2013, and to the relatively high frequency of NPS springs supported by small, mountain aquifers that do not support persistent springs, and these are in gullies where flooding is common. Differences may also be attributed to the large number of valley floor springs that are supported by relatively large recharge provided by snow accumulated on more than 150 Great Basin and Mojave Desert mountain ranges. The large number of persistent, valley floor and bajada springs in this region provides stable environments that are required by crenophiles, and that are uncommon in NPS springs.

Our observations also differ from conditions reported by Abele (2011), who also used Sada and Pohlmann (2006) sampling protocols to survey springs in Nevada. These surveys found that the condition of some springs had declined over 20 years and that it improved in others, and that there was no net change in condition among springs over this period. Differences between those observations and our more extensive surveys may be attributed to their focused examination of ‘high priority’ springs, which are all occupied by crenophiles, and may be in better condition than the broad diversity of springs across the landscape. Abele (2011) did not tally crenophile extirpations and declines.

Table 12. The number of springs in Chihuahuan Desert (CHDN) and Mojave Desert (MOJN) Networks of National Parks surveyed during 2007- 2011, and the percent of springs in each park that were dry or exhibited evidence of periodic drying and scouring, disturbance by human factors, and the percent that were undisturbed by human or natural factors. Creno. Spp. = the number of crenophilic species known from springs in each park. BIBE = Big Bend, GUMO = Guadalupe Mtns., CAVE = Carlsbad Caverns, JOTR = Joshua Tree, and DEVA = Death Valley National Parks, WHSA = White Sands and PARA = Grand Canyon-Parashant National Monuments, and LAME = Lake Mead National Recreation Area. Many springs were affected by more than one disturbance. Data compiled in Sada (2013).

Park	No. Spgs.	Dry	Scoured	Human	Not Dry/Scour	Undisturbed	Creno. Spp.
CHDN							
BIBE	257	81	46	18	19	17	0
GUMO	25	41	68	23	23	10	0
CAVE	38	39	22	68	20	0	0
WHSA	4	0	100	0	0	0	0
MOJN							
LAME	89	36	46	46	29	6	3
JOTR	109	33	65	17	0	0	0
PARA	206	46	28	66	13	< 0.1	1
DEVA	809	48	34	30	25	16	11

Our assessment of temporal changes in spring condition also found that the condition of some springs improved, others had not changed, but, contrary to Abele (2011), conditions had deteriorated in more than 44 percent of 265 springs that had been visited more than once since the late1980s.

The degraded condition of more than 65 percent of Great Basin and Mojave Desert springs, extirpation, extinction, or severe declines of 34 crenophilic taxa from the late 1980s into 2013, and continued declines in spring condition show that these systems may be one of the most endangered ecosystems in North America. These findings also show current and past management have not protected the ecological health of these systems, and the focus to improve the health of streams, rivers, and lakes has not been applied to springs. New strategies are necessary to prevent additional declines in the quality of isolated wetlands in this arid environment. Continued extirpations also begs two questions, 1—'What has been lost that was never recorded from these systems?', and 2—'What will disappear next?'

Springs are distinctive aquatic and riparian systems that function differently from other lentic and lotic environments (see McCabe 1998). Due to these differences, it is inappropriate to manage and restore springs using many of the tools that effectively manage lentic and lotic habitats. Unfortunately, many springs have been degraded, their functional characteristics altered, and invasive species habitats have been created by practitioners employing incompatible methods. Springs appear to be very sensitive to disturbance but Keleher and Radar (2008) and Sada et al. (2015) also observed that their ecological health is minimally affected with minimal levels of disturbance. In contrast, Morrison et al. (2013) found tipping points where springbrook environments were most severely altered when discharge was reduced less than 20 percent. Sada et al. (2015) found the structure and functional characteristics of a BMI community also changed when discharge was reduced by 20 percent.

RECOMMENDATIONS

Several key elements of change are needed to management springs and stop their continued deterioration, and informed, innovative restoration programs are needed to return springs to naturally functioning condition. These are:

- Training: Springs are not streams or lakes, and few springs are ecologically healthy. The paucity of healthy springs makes it difficult for practitioners and managers to identify healthy springs. Without this background, it is not possible to set appropriate management and restoration goals. Training is needed to educate practitioners and managers about healthy and unhealthy spring systems. This background is needed to implement proper management strategies.
- Reference conditions: Springs that are in good condition are rare, which makes it difficult to identify management goals and design appropriate restoration programs. Springs are diverse in their landscape associations, water chemistry, morphology, and geographic location, and setting a single set of management goals or restoration strategies for all

springs is not ecologically appropriate. For instance, goals will differ between springs on mountains and springs discharging next to playas. Additional surveys are needed to locate reference sites that represent high quality springs in different landscape settings and fed by different types of aquifers. This is needed to provide a broad perspective that quantitatively describes ecological healthy systems.

- Restoration Programs: A number of restoration programs have been implemented in Nevada. Some have been successful (e.g., Duckwater Big Warm Springs, Red Spring, several Ash Meadows springs), but a number have not (Duckwater Little Warm Springs, Preston Big Spring, Torrance Ranch Springs). Successful programs have returned each spring to its naturally functioning condition, and unsuccessful programs have either used inappropriate methods (e.g., hydraulic models to determine channel morphology) or created habitats preferred by practitioners (e.g., pools), rather than functional aspects that accurately characterize the target spring. All unsuccessful programs have functionally changed the habitat and created conditions that support invasive species (e.g., bullfrogs, mosquito fish, cattails, etc.), and prevents restoration of healthy spring systems.

ACKNOWLEDGEMENTS

Surveys were funded by the Smithsonian Institution, U.S. Bureau of Land Management, U.S. National Park Service, the Southern Nevada Water Authority, City of Los Angeles Department of Water and Power, The Nature Conservancy, Nevada Heritage Program, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, U.S. Forest Service, and U.S. Geological Survey. Surveys were collected by R. Hershler (Smithsonian Inst.), D. Sada, C. Rosamond, and A. Schwaneflugel (Desert Research Inst.), G. Vinyard (University of Nevada Reno, P. Hovingh (Veterans Memorial Hospital, Salt Lake City), and E. Miskow (Nevada Heritage Program). Funding for this report was provided by The Great Basin Landscape Conservation Cooperative.

REFERENCES

Abele, S.L. (ed). 2011. Nevada Springs Conservation Plan. The Nature Conservancy, Reno, NV.

Anderson, T.M and N.H. Anderson. 1995. The insect fauna of spring habitats in semiarid rangelands in central Oregon. Pages 65-76. *In*, L.C. Ferrington (ed.). Biodiversity of Aquatic Insects and Other Invertebrates in Springs. Journal of the Kansas Entomological Society 68.

Baldinger, A.J., W.D. Shepard, and D.L. Threloff. 2000. Two new species of *Hyalella* (Crustacea: Amphipoda: Hyalellidae) from Death Valley National Park, California, U.S.A. Proceedings of the Biological Society of Washington 113:443-457.

Blinn, D.W. 2008. The extreme environment, trophic structure, and ecosystem dynamics of a large, fishless desert spring. Pages 98 – 126. *In*, L.E. Stevens and V.J. Meretsky (eds.). Aridland Springs of North America. Ecology and Conservation. University of Arizona Press, Tuscon, AZ.

Botosaneau, L (ed.). 1998. Studies in Crenobiology. The Biology of Springs and Springbrooks. Backhuys Publishers, Leiden, The Netherlands.

Darlington, D. 1996. The Mojave. A Portrait of the Definitive American Desert. Henry Holt and Company, NY.

Echelle, A.A. 2008. The western North American pupfish clade (Cyprinodontidae:*Cyprinodon*): Mitochondrial DNA divergence and drainage history. Pages 27-38. *In*, M.C. Reheis, R. Hershler, and D.M. Miller (eds.). Late Cenozoic Drainage History of the Southwestern Great Basin and Lower Colorado River Region: Geologic and Biotic Perspectives. Geological Society of America Special Paper 439.

Elton, C. 1927. Animal Ecology. The MacMillian Co., New York.

Erman, N.A. 1992. Factors determine biodiversity in Sierra Nevada cold spring systems. Pages 119-127. *In*, C.A. Hall, V. Doyle-Jones and B. Widawski (eds.). The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains. University of California, White Mountain Research Station Symposium, Volume 4.

Erman, N.A. and D.C. Erman. 1995. Spring permanence, Trichoptera species richness, and the role of drought. Journal of the Kansas Entomological Society 68:50-64.

Feldmeth, C.R., E.A. Stone, and J.H. Brown. 1974. An increased scope for thermal tolerance upon acclimating pupfish (*Cyprinodon*) to cycling temperatures. Journal of Comparative Physiology 89:39-44.

Ferrington, L.C. (ed.). 1995. Biodiversity of Aquatic Insects and Other Invertebrates in Springs. Journal of the Kansas Entomological Society 68.

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

Forbes, C.A. 1887. The lake as a microcosm. Illinois natural History Survey Bulletin 15:537-550.

Forrester, R.M. 1991. Ostracode assemblages in springs in the western United States: Implications for paloehydrology. Pages 181-201. *In,* D.D. Williams and H.V. Danks (eds.). Arthropods in Springs, with General Reference to Canada. Memoirs of the Entomological Society of Canada, No. 155.

Fowler, C.S. 2002. What's in a Name: Some Southern Paiute Names for Mojave Desert Springs as Keys to Environmental Perception. Conference Proceedings. Spring-fed Wetland: Important Scientific and Cultural Resources of the Intermountain Region, 2002. D.W. Sada and S. Sharpe (eds.). http://www.dri.edu/spring-fed-wetlands.

Grasyson, D.K. 2011. The Great Basin. A Natural Prehistory. University of California Press. Berkeley, CA.

Hershey, R.L., S.A. Mizell, and S. Earman. 2010. Chemical and physical characteristics of springs discharging from regional flow systems of the carbonate-rock province of the Great Basin, western United States. Hydrogeology Journal DOI 10.1007/s10040-009-0571-7.

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

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

Howard, J.K., K.R. Klausmeyer, K.A. Fesenmyer. J. Furnish, et al. 2015. Patterns of freshwater species richness, endemism, and vulnerability in California. PLOS ONE, DOI:10.1371/journal.pone.0130710.

Hubbs, C. 1995. Springs and spring runs as unique aquatic habitats. Copeia 1995:989-991.

Hynes, H.B.N. 1970. The Ecology of Running Waters. University of Toronto Press, Toronto.

Keleher, M.J. and D.W. Sada. 2012. Desert Spring Wetlands of the Great Basin. Pages 329-341. *In*, D.P. Batzer and A.H. Baldwin (eds.). Wetland Habitats of North America. University of California Press, Berkeley, CA.

Keleher, M.J. and R.B. Radar. 2008a. Dispersal limitations and history explain community composition of metaphyton in desert springs of the Bonneville Basin, Utah: A multiscale analysis. Limnology and Oceanography 53:1604-1613.

Keleher, M.J. and R.B. Radar. 2008b. Bioassessment of artesian springs in the Bonneville Basin, Utah, USA. Wetlands 28:1048-1059.

Lindeman, R.L. 1942. The trophic-dynamic aspect of ecology. Ecology 23:399-419.

Livingston, S.D. 2002. The Relevance of Old Dirt and Old Water to Location, Preservation, and Visibility of Prehistoric Archaeological Sites in the Great Basin. Conference Proceedings. Spring-fed Wetland: Important Scientific and Cultural Resources of the Intermountain Region, 2002. D.W. Sada and S. Sharpe (eds.). http://www.dri.edu/spring-fed-wetlands.

McCabe, D.J. 1998. Biological communities in springbrooks. Pages 221-228. *In*, L. Botosaneau (ed.). Studies in Crenobiology. The Biology of Springs and Springbrooks. Backhuys Publishers, Leiden, The Netherlands.

Meffe, G.K. and P.C. Marsh. 1983. Distribution of aquatic macroinvertebrates in three Sonoran Desert springbrooks. Journal of Arid Environments 6:363-371.

Meinzer, O.E. 1923. Outline of ground water hydrology, with definitions. U.S. Geological Survey Water Supply Paper 494.

Miller, R.R. 1961. Man and the changing fish fauna of the American southwest. Papers of the Michigan Academy of Science, Arts, and Letters 46:365-404.

Miller, R.R. 1948. The cyprinodont fishes of the Death Valley System of eastern California and southwestern Nevada. Miscellaneous Publications of the Museum of Zoology, University of Michigan 68:1-155.

Minckley, W.L. and J.E. Deacon. 1968. Southwestern fishes and the enigma of 'endangered species'. Science 159:11424-1432.

Morrison, R., M. Stone, and D.W. Sada. 2013. Response of a desert springbrook to incremental discharge reductions, with tipping points of non-linear change, Death Valley National Park, California, USA. Journal of Arid Environments 99:5-13.

Myers, M.J. and V.H. Resh. 1999. Spring-formed wetlands of the arid west. Islands of aquatic invertebrate biodiversity. Pages 811- 828. *In,* D.P. Batzer, R.B. Radar, and S.A. Wissiner (eds.). Invertebrates in Freshwater Wetlands of North America: Ecology and Management. John Wiley and Sons, New York, NY, USA.

Myers, M.J., F.A.H. Sperling, and V.H. Resh. 2001. Dispersal of two species of Trichoptera from desert springs: Conservation implications for isolated and connected populations. Journal of Insect Conservation 5:207-215.

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

Odum, H.T. 1957a. Trophic structure and productivity of Silver Springs, Florida. Ecological Monographs 27:55-122.

Odum, H.T. 1957b. Primary production measurements in eleven Florida springs, and a marine turtle grass community. Limnology and Oceanography 2:85-97.

Pavlik, B.M. 2008. The California Deserts. An Ecological Rediscovery. University of California Press. Berkeley, CA

Polhemus, D.A. and J.T. Polhemus. 2002. Basin and ranges: The biogeography of aquatic true bugs (Insecta:Hemiptera) in the Great Basin. Pages 235 – 224. *In*, R. Hershler, D.B. Madsen, and D.R. Currey (eds.). Great Basin Aquatic Systems History. Smithsonian Contributions to Earth Sciences, Number 33.

Sada, D.W. 2013. Environmental and Biological Characteristics of Springs in the Chihuahuan Desert Network of National Parks, with a Prioritized Assessment of Suitability to Monitor for Effects of Climate Change. Unpublished report to U.S. National Park Service, Chihuahuan Desert Inventory and Monitoring Network, Las Cruces, NM.

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

Sada, D.W. 1990. Recovery Plan for the Threatened and Endangered Species of Ash Meadows, Nevada. U.S. Fish and Wildlife Service, Portland, OR.

Sada, D.W. and J.M. Thomas. In Review. Integrating hydrogeology and aquatic ecology across landscapes: A global perspective from western USA deserts. Journal of Freshwater Sciences.

Sada, D.W. and C.A. Jacobs. 2008. Environmental and Biological Characteristics of Springs in Lake Mead National Recreation Area, Nevada and Arizona. Unpublished report to the U.S. National Park Service, Lake Mead National Recreation Area, Boulder City, NV.

Sada, D.W. and K.F. Pohlmann. 2007. Environmental and Biological Characteristics of Springs in Death Valley National Park, California and Nevada. Unpublished report to the U.S. National Park Service, Death Valley National Park, Death Valley, CA. Great Basin Cooperative Ecosystem Study Unit Task Agreement No. J8R07050014.

Sada, D.W. and K.F. Pohlmann. 2006. Level 1 Spring Survey and Inventory Protocols. U.S. National Park Service, Mojave Inventory and Monitoring Network. Unpublished report to the U.S. National Park Service, Mojave Inventory and Monitoring Network, Boulder City, NV.

Sada, D.W. and S.E. Sharpe (eds.). 2002. Conference Proceedings. Spring-fed Wetland: Important Scientific and Cultural Resources of the Intermountain Region. http://www.dri.edu/spring-fed-wetlands.

Sada, D.W. and G.L. Vinyard. 2002. Anthropogenic changes in historical biogeography of Great Basin aquatic biota. Pages 277- 292. *In*, R. Hershler, D.B. Madsen, and D.R. Currey (eds.). Great Basin Aquatic Systems History. Smithsonian Contributions to Earth Sciences, No. 33.

Sada, D.W. and J.L. Nachlinger. 1998. Spring Mountains Ecosystem: Vulnerability of Spring-Fed Aquatic and Riparian Systems to Biodiversity Loss: Part II, Springs Surveyed in 1997. Unpublished report to U.S. Bureau of Land Management, Las Vegas, Nevada.

Sada, D.W., K. Acharya, and K. Mehler. 2015. Qualitative and Quantitative Assessment of the Ecological Health of Nevada's Spring Ecosystems. Unpublished report to the Nevada Heritage Program, Carson City, NV.

Sada, D.W., E. Fleishman, and D.D. Murphy. 2005. Associations among spring-dependent aquatic assemblages and environmental and land use gradients in a Mojave Desert mountain range. Diversity and Distributions 11:91-99.

Sada, D.W., J.E. Williams, J.C. Silvey, A. Halford, et al. 2001. Riparian Area Management. A Guide to Managing, Restoring, and Conserving Springs in the Western United States. Technical Reference 1735-17. Bureau of Land Management, Denver, Co. BLM/ST/ST-01/001+1737.

Schrode, J.B. and S.D. Gerking. 1977. Effects of constant and fluctuating temperatures on reproductive performance of a desert pupfish, *Cyprinodon n. nevadensis*. Physiological Zoology 48:378-389.

Shepard, W.D. 1993. Desert springs—both rare and endangered. Aquatic Conservation: Marine and Freshwater Ecosystems 3:351-359.

Smith, G.R., T.E. Dowling, K.W. Gobalet, T. Lugaski, D.K. Schiozawa, and R.P. Evans. 2002. Biogeography and timing of evolutionary events among Great Basin fishes. Pages 145 – 174. *In*, R. Hershler, D.B. Madsen,and D. Currey (eds.). Great Basin Aquatic Systems History. Smithsonian Contributions to the Earth Sciences No. 33.

Springer, A.E. and L.E. Stevens. 2009. Spheres of discharge of springs. Hydrogeology Journal 17:83-93.

Stevens, L.E. and V.J. Meretsky (eds,). 2008. Aridland Springs in North America. Ecology and Conservation. University of Arizona Press. Tucson, AZ.

Thomas, J.M., A.H. Welch, and M.D. Dettinger. 1996. Geochemistry and isotope hydrology of representative aquifers in the Great Basin region of Nevada, Utah, and adjacent states. U.S. Geological Survey Professional Paper 1409-C.

Unmack, P.J. and W.L. Minckley. 2008. The demise of desert springs. Pages 11 – 34. *In*, L.E. Stevens and V.J. Meretsky (eds.). Arid Land Springs in North America. Ecology and Conservation. University of Arizona Press. Tucson, AZ.

Van der Kamp, G. 1995. The hydrology of springs in relation to biodiversity of spring fauna: A review. Pages 4-17. *In*, L.C. Ferrington (ed.). Biodiversity of Aquatic Insects and Other Invertebrates in Springs. Journal of the Kansas Entomological Society 68 (2) supplement. Special Publication No. 1.

Weigert, R.G. and R. Mitchell. 1973. Ecology of Yellowstone thermal effluent systems: Intersects of blue-green algae, grazing flies (*Paracoenia*, Ephydridae) and water mites (*Partnuniela*, Hydrachnellae). Hydrobiologia 41:251-271.

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

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. Journal of Geology 30:377-392.

Williams, D.D. and H.V. Danks. 1991. Arthropods of srings with particular reference to Canada. Memoirs of the Entomological Society of Canada, No. 155.

Williams, J.E., D.B. Bowman, J.E. Brooks, A.A. Echelle, R.J. Edwards, D.A. Hendrickson, and J.J. Landye. 1985. Endangered aquatic ecosystems in North American deserts, with a list of vanishing fishes of the region. Journal of the Arizona-Nevada Academy of Science 20:1-62.

APPENDIX A: GLOSSARY

Abiotic	Non-living, lifeless.
Anthropogenic	Factors caused or produced by humans or their activities.
Crenophile(ic)	An obligate, spring associated organism.
Electrical conductance (EC)	Ability of a substance to transmit electricity.
Endemic	Native to a particular geographic region.
Helocrene	A spring source that is shallow and marshy.
Limnocrene	A spring source that is a deep pool.
Lentic	Non-flowing aquatic habitats such lakes and ponds.
Lotic	An aquatic habitat with flowing water.
Rheocrene	A spring where water discharges at the source into a flowing channel.
Spatial fluctuations	Fluctuations that occur in different areas.
Springbrook	A channel that carries water flowing from a spring.
Spring province	A group of springs in close geographical proximity.
Thermal	Warm or hot.
Thermophiles	Plants and animals that only occupy thermal habitats.
Temporal fluctuation	Fluctuations that occur over time.

APPENDIX B: DATABASE ELEMENTS

INTRODUCTION

The Springs Database includes records for approximately 2,200 springs visited in Nevada, California, Oregon, Utah, Idaho, Wyoming, and Arizona from the late 1980s to the present. Additional records will be added as surveys are conducted. Most of these surveys were conducted during biogeographic and taxonomic studies for Great Basin springsnails (Family Hydrobiidae) and funded by the Smithsonian Institution and U.S. Bureau of Land Management. Data from a number of additional surveys (many of them examining different aspects of spring ecology) are also included (these have primarily been conducted by D. Sada, D. Herbst (University of California), and J. Nachlinger (The Nature Conservancy). Other funding for surveys has been provided by the Southern Nevada Water Authority, City of Los Angeles Department of Water and Power, The Nature Conservancy, the U.S. Fish and Wildlife Service, U.S. Forest Service, and U.S. Geological Survey. This is a dynamic database that grows continuously from additional survey work, and is not a perfect document. Please notify Donald Sada with questions or revisions (don.sada@dri.edu).

This database contains three types of information: 1—Data that identify spring location and salient abiotic features of habitat (e.g., basic water chemistry, spring morphology, aquatic habitat characteristics, and a qualitative assessment of disturbance). The database includes approximately 50 elements (cells) that describe site location, land ownership, habitat features, and the presence of notable species. The field form used for most surveys is shown in Appendix A.

Information for these sites consists of locations and the presence or absence of springsnails. Blank cells, ND, and '---' in the database are data elements that were not recorded. 2—Notable species observed at each spring. The presence or absence of springsnails at each spring is well documented, but the occurrence of other taxa (e.g., amphibians, ostracodes, other mollusks) is less exact because these organisms are often difficult to locate due to their scarcity or daily habits (e.g., nocturnal). Additional surveys, possibly using different survey techniques, are required to accurately determine the presence or absence of these species. Important vegetation was not recorded prior to 2004 surveys. 3—Written reports and peer- reviewed articles that either involve or mention the spring.

ELEMENTS

- Date: The date that a survey was conducted.
- Surveyor: The lead person conducting the survey on the date listed. Includes initial of given name and surname (e.g., JSmith).
- Field Note Number: The field note number that was recorded by the surveyor for the survey.
- Spring Name: The spring name that is shown on USGS topographic maps. If no name was shown, a name was given, often to indicate general spring location.
- State: The state where the spring is located. Recorded as the standardized abbreviation used by the U.S. Postal Service (e.g., CA = California, NV = Nevada).
- County: The county where the spring is located.
- Drainage Basin: The drainage basin where the spring is located. If the spring is located within a river basin, the river basin was listed (e.g., Colorado River, Humboldt River). If it occurs within an endorheic (enclosed) basin, the valley name was recorded.
- Spring Location: The location of each spring is shown by map and GPS coordinates.
    - Map Coordinates: Township, Range, and Quarter-Section coordinates were recorded from USGS 1:100,000 scale topographic maps.
    - Map Name: The name of the USGS 1:100,000 scale topographic map where the spring is located.
    - Global Positioning System (GPS) (NAD 83): GPS location of the spring source. Recorded in UTMs (to the nearest meter). PDOP was recorded when UTMs were recorded in the field, but early 1990s surveys were conducted prior to GPS technology. UTM coordinates for these surveys were compiled using Topo® (National Geographic Society 2000). When UTMs were determined from in this program, ‘map’ occurs in the PDOP cell.
    - ±: The number of meters for the GPS error
- Vehicle access: Recorded as positive or negative. Road access ranges from pavement to 4-wheel drive.
- Photos: Photos were taken at most sites visited during the 1990s, and these have been digitally transferred from color slides. More recent photos are digital. Each photo is labeled

according to the field note number assigned by the surveyor. The survey form includes space to record the UTMs where each photo is taken. The most informative photos show the spring source, the springbrook, and the landscape context where the spring occurs.

- Land ownership: Recorded as shown on U.S. Bureau of Land Management Surface Management Status Maps. Boundaries on these maps are approximate and this information may not be highly accurate. Also, land ownership may change, and current land ownership is maintained only in official county records. Ownership is abbreviated as U.S. National Park Service (NPS), U.S. Forest Service (USFS), U.S. Bureau of Land Management (BLM), Tribal, Military, Private, City of Los Angeles Department of Water and Power (LADWP), U.S. Fish and Wildlife Service (USFWS), State, etc..

- Elevation: For 1990s surveys elevation was measured using a Thommen mechanical altimeter that was calibrated from topographic maps several times each day. Elevation was measured using a GPS unit when UTMs were recorded. Elevation in meters and feet above seal level are shown.

- Spring/Habitat Type as: A spring is where water flows naturally from rock or soil onto the land or into a body of water. The flow onto the surface under many different conditons, and in many shapes and sizes. Hydrologists have identified a number of different 'types' (morphologies) (e.g., Springer and Stevens 2009), but this database shows only the basic types that have been used for decades (e.g., Hynes 1970). These types are: **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), or **Helocrene** (similar to a Limnocrene, but marshy and comparatively shallow, not an open pond or pool). In some areas, springs were excavated by native peoples or settlers to create a **D—Qanat (**a hand-dug well) or mechanically dug **Wells** (usually with rock, metal, or plastic casing). Qanats are found where surface water is regionally scarce. Identifying spring type is difficult at sites that have been disturbed by cultural activities that have impounded springs using dikes, the spring source replaced with a spring box (concrete, wooden, plastic, and metal containers), or filled to capture water in a pipe that leads to a trough. In these situations, spring type is listed as **Unknown**.

- Spring Discharge: Estimated in liters/minute. Values recorded are qualitative because it is difficult to estimate discharge because most springs are small, water is usually shallow and broadly and unevenly spread over a wide area, and areas with moving water are often very limited. Accuracy is also difficult because discharge often changes throughout the day, seasonally, or annually, which minimizes the effectiveness of single measurements to precisely quantify long-term discharge characteristics. Although it is difficult to accurately record discharge, when these estimates are considered with springbrook length, water depth, and wetted width, the relative size of a spring is revealed (ergo springs with longer springbrooks, and deeper and wider water have greater discharge than shallow springs with narrower and shorter springbrooks).Blanks represent sites were discharge was not estimated.

- Springbrook Length: Estimated in meters. Blanks represent sites were springbrook length was not estimated.
- Water Depth: The estimated average water depth (cm) occurring in the springbrook. Blanks represent sites were water depth was not estimated.
- Wetted Width: The estimated average width of water (cm) measured across a springbrook and perpendicular to the direction of flow. Blanks represent sites were wetted width was not estimated.

WATER CHEMISTRY

All water chemistry parameters were measured as close to a spring source as possible.

- Dissolved Oxygen Concentration (D.O., in mg/liter): Measured using a field meter (e.g., YSY, Oakton, etc.) (estimated error ± 1 mg/l). Blanks represent sites were dissolved oxygen was not measured.
- Water Temperature (degrees Centigrade): Measured with the meter that also measures D.O. or conductivity (estimated error ± 2°C). Blanks represent sites were temperature was not measured.
- Electrical Conductance (conductivity or EC): Measured in µmhos using a field meter (e.g., YSY, Oakton, etc) (estimated error ± 10 percent of measured value). Blanks represent sites were EC was not measured.
- pH: Measured using a hand-held field meter that can be calibrated (such as the pHtestr2) (estimated error ± 10 percent of measured value). Blanks represent sites were pH was not measured.

AQUATIC HABITAT ASSESSMENT AND NOTABLE SPECIES

- Emergent Cover: Qualitatively estimated (to the nearest 10 percent) as the percent that riparian and instream vegetation, debris, or other material arising within the wetted perimeter that shaded springbrook substrate. Blanks represent sites were cover was not estimated.

- Vegetative Bank Cover: Qualitatively estimated (to the nearest 10 percent) as the percent that live vegetation covers springbrook banks within the riparian zone. Blanks represent sites were bank cover was not estimated.
- Substrate Composition: Qualitatively estimated (to the nearest 5 percent for each category) using a Wentworth particle scale analysis (Wentworth 1992), which describes the substrate by the proportional composition of materials that are classified as: Fines (<1 mm), Sand (1 mm to 5 mm), Gravel (>5 mm to 80 mm), Cobble (>80 mm to 300 mm), Boulder (>300 mm), or bedrock. Size is defined as the minimum particle size, of substrate as measured on a two-dimensional axis, that would pass through a substrate sieve. Total percent composition must = 100 percent (estimated error $\pm$ 10 percent for each category). Blanks occur where substrate categories did not occur in a spring.
- Notable Species: The presence of important animals (ergo springsnails, amphipods, fish, ostracodes, clams, pulmonate gastropods, amphibians, and non-native species) was recorded during all surveys when they were observed. Not seeing them during a survey does not indicate they were absent. They may be found at a spring if more intensive surveys were conducted. Taxa were identified to species when possible (often it is difficult to identify species because of life stage (e.g., amphibians as tadpoles). When specific identification was not possible, the presence of animals within any of the above groups is recorded (e.g., unknown fish, unknown amphibian, unknown bat, etc.).
- Non-native species recorded include salt cedar (*Tamarisk* sp.), palm trees (Family Arecaceae), arundo (*Arundo donax)*, and white top (*Cardaria pubescens)*. The most likely non-native animals include mosquito fish (*Gambusia affinins)*, bass (*Micropterus* sp.), trout, crayfish, and red-rimmed melania (*Melanoides tuberculata)*.
- Watercress (*Rorripa* sp.) was the only plant species recorded in surveys conducted prior to 2000, after this the presence of other important riparian species was recorded (see the field form for a list). Notable wetland vegetation included rushes (Family Juncaceae), cattails (*Typha* sp.), reeds (*Scirpus* sp.), water cress (*Rorippa* sp.), spikerush (*Eleocharis* sp., yerba mansa (*Anemopsis californica)*, mesquite (*Prosopis* sp.), wild rose (*Rosa* sp.), cottonwood (*Populus freemontii*), willow (*Salix* sp.), or other large woody vegetation in a springbrook or riparian zone. Notable plant species (with the exception of *Rorippa* sp.) were not recorded before 2004 surveys. Vegetation records focus on trees and wetland and upland vegetation to facilitate the assessment of spring condition and permanence (e.g., upland species in the riparian zone indicate impermanent or highly degraded springs, wetland species indicate healthy and permanent springs).

SITE CONDITION EVALUATION

Site Condition: Cultural activities have disturbed most springs and 'pristine' springs are rare. It is often difficult to determine whether or not an 'undisturbed' spring was disturbed in the past, or if it has naturalized from historical disturbance. In the database, the current condition, and activities affecting the condition of each spring are recorded. If a spring had naturalized from past disturbance, this information is recorded in the Notes Section. Sites are categorized as undisturbed, slightly disturbed, moderately disturbed, or highly disturbed by cultural (human) or natural factors, which appear to have similar effects on aquatic and riparian communities. Natural disturbances listed in the database include avalanche, flood, fire, and drought (e.g., ephemeral springs). Cultural disturbances include diversion (e.g., a spring box installed in the source to capture water in a pipe and divert it to a trough, diversion into concrete or channelized canals, impounded, etc.), ungulates (wild horses and burros, elk), cattle, and recreation. Undisturbed and slightly disturbed springs have generally higher species richness and fewer non-native species than moderately and highly disturbed springs. Many springs have been affected by several of these factors, which are recorded in the database. Data compiled in the database code these categories as: 1 = undisturbed, 2 = slight disturbance, 3 = moderate disturbance, and 4 = highly disturbed, for each of the factors listed above.

DISTURBANCE CATEGORIES ARE DESCRIBED AS:

- Undisturbed sites appear unaffected by recent or historical activity. All sites that appear to be unaffected by cultural or natural factors should be categorized as undisturbed. For example, there is no evidence of livestock use, diversion, or recreation.
- Slightly disturbed sites exhibit little evidence that vegetation or soil had been disturbed. These are springs where vegetation shows limited evidence of browsing and foraging, and diversion is inefficient with little water being removed from the springbrook. Animal footprints and scat may be prominent but vegetation is robust. Evidence of fire or flooding in the distant past may have been visible. The spring is being used, but its functional characteristics have not been compromised.
- Moderately disturbed sites show signs of recent disturbance. Use may be intense and functional characteristics of the spring are compromised. Vegetation covers > 50 percent of the springbrook banks, and at least 50 percent of natural discharge remains within the natural springbrook. Neither the spring nor springbrook has been impounded, but evidence of flooding or fire has reduced spring bank vegetation to coverage levels mentioned above.

Cultural factors disturbing these springs usually include grazing (cattle, wild horses and burros, elk), diversion (e.g., into pipes, canals, troughs, or impounded), or recreation (picnicking, off-road vehicles, etc.).

- Highly disturbed and undisturbed springs have little similarity. Less than 50 percent of their banks are covered with vegetation, their springbrooks contain < 50 percent of natural discharge, they are impounded or dredged, or spring boxes are installed to collect water. Springs affected by drought (ergo seasonal dry conditions) are also categorized as highly disturbed because the disturbance of drought and drying has an overwhelming influence on aquatic and riparian communities. Springs recently affected by fire and subjected to frequent flooding (often located in the bottom of arroyos) are also categorized as highly disturbed. Cultural factors that disturb these springs usually include intensive ungulate grazing, diversion into pipes, canals, or troughs, spring box construction, dredging, or recreation.
- Influences Causing Disturbance: A relatively limited number of cultural and natural factors affect arid land springs. These include avalanche, fire, flooding, drought (natural drying), diversion (including impoundment, capture in pipe, spring box, or into canal), ungulates (wild horses and burros, elk), cattle, and recreation. Disturbance at many springs is caused by multiple factors such as intensive livestock grazing around a trough, or heavy recreation use along a springbrook (that tramples vegetation) where water is channelized away from areas used for picnicking.
- References: include literature focusing on spring ecology and crenophilic species that are known from individual sites. References focus on springsnail taxonomy, which includes the most substantial literature examining Great Basin spring biota.
- Notes: These are general comments about the spring location, condition, etc. This also includes a qualitative assessment of the relative abundance of springsnails during the survey.

Spring Survey Field Form

FIELD NOTE #:-__________ SURVEYOR: _____ DATE: ______________

STATE: NV COUNTY: ______ LOCALITY: ______________________________

LOCATION ID: ____

DRAINAGE: _______________ T ____ R____ ¼ SEC _____

1:100,000 USGS QUAD: ____________GPS ZONE: ____ ±m ______

PDOP: ______ DATUM: NAD:83 ACCESS: _____ ELEVATION (M):______

SOURCE GPS POINT: PHOTO #1: NORTHING:___________EASTING:____________

DOWNSTREAM PHOTO #2: NORTHING:___________ EASTING:______________

UPSTREAM PHOTO #3: NORTHING:______________ EASTING:_______________

______________PHOTO #4: NORTHING: ___________ EASTING: ____________

______________PHOTO #5: NORTHING:____________________ EASTING:______________________

Vegetation	
Willow	*Salix* sp.
Mesquite	*Prosopis* sp.
Cattails	*Typha* sp
Rushes	Juncaceae
Spikerush	*Eleocharis* sp.
Reeds	*Scirpus* sp.
Salt Grass	*Distichlis spicata*
Phragmytes	*Phragmytes australis*
Wild Rose	*Rosa woodsii*
Grapevine	*Vitis sp.*
Cottonwood	*Populous freemontii*
Watercress	*Rorippa* sp.
Palm tree	Arececeae
White Top	*Cardaria pubescens*
Salt Ceder	*Tamarix* sp.
Arundo	*Arundo donax*
Sedge	*Carex* sp.

OWNER: NPS USFS BLM TRIBAL MILITARY PRIVATE OTHER_____________

SPRING TYPE: HELOCRENE RHEOCRENE LIMNOCRENE DRY QANAT CASED WELL UNKN OTHER________

ESTIMATED DISCHARGE (L/MIN.) :____________ SPRINGBROOK LENGTH (M): ____________________

AVERAGE WATER DEPTH (CM): __________ AVERAGE WATER WIDTH (CM): ________ DO (MG/L:) __________

TEMPERATURE (°C) :__________ SALINITY (PPT) :__________ CONDUCTIVITY (µS OR mS): ____________

pH ____ 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:______________

IMPORTANT ANIMALS: NONE SPRINGSNAILS (Scarce; Common; Abundant) FISH CLAMS AMPHIPODS PULMONATES

COLLECTIONS MADE: ______________________________ MUSEUM DEPOSITED: _________________

OTHER NON-NATIVE SPECIES: ____

OTHER VEGETATION: ____

OTHER FAUNA: ____

SITE CONDITION: undisturbed slight moderate high

DISTURBANCE: livestock recreation diversion residence drying fire flooding dredging other_________________

NOTES:____

____

____

____

____

SKETCH OF AREA ON BACK

APPENDIX C: PHOTOGTRAPHS OF REPRESENTIVE SPRINGS WITH DIFFERENT DISTURBANCE LEVELS

Figure C1. Undisturbed spring. Unnamed cold spring, Soldier Meadow, Humboldt County, NV (spring ID No. 2530, Field Note No. CR13-12). June 18, 2013.

Figure C2. Slight disturbance condition. Blue Point Spring, Lake National Recreation Area, Clark County, NV (spring ID No. 80, Field Note No. CR12-19).

Figure C3. Moderate disturbance condition. Specie Spring, Clark County. May 22, 2012. NV (spring ID No. 775, Field Note No. CR12-04).

Figure C4. Moderate disturbance condition, caused by ungulates. Unnamed spring North of Cherry Creek, Steptoe Valley, White Pine County, NV (spring ID No. 2056, Field Note No. CR12-54).

Figure C5. High disturbance condition, caused by ungulates. Unnamed spring North of Cherry Creek, Steptoe Valley, White Pine County, NV (spring ID No. 2057, Field Note No. CR12-55).

Figure C6. High disturbance condition, caused by diversion and ungulates. Unnamed Spring, 2 km SE of Lida, County, Nevada. May 22, 2012 NV (spring ID No. 390, Field Note No. CR12-01).

Figure C7. High disturbance condition, caused by diversion and recreation. White Rock Spring, Clark County, Nevada. May 25, 2012 NV (spring ID No. 3, Field Note No. CR12-16).