Quantitative and Qualitative Assessment of the Ecological Health of Nevada's Desert Spring Ecosystems

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ABSTRACT

Nevada springs are small riparian and aquatic systems. They occur over all aspects of the landscape, and each spring is distinguished by physicochemical characteristics of its environment. They are often the only surface water over vast areas, and most have been altered for and by non-native ungulates, recreation, diversion and impoundment, and groundwater use. Many springs are also occupied by non-native species. These factors have caused extinctions and extirpated populations of crenophilic species, but methods to assess the ecological consequences of less severe human activities have not been developed.

Benthic macroinvertebrates (BMIs) and metrics describing physicochemical characteristics of 115 randomly selected springs were sampled in Nevada during 2012 and 2013. Seven were dry, and five flowing springs did not support BMI communities. Disturbance of each spring was qualitatively categorized as undisturbed, slightly, moderately, and highly disturbed by human (livestock, diversion, recreation, etc.) and natural (drying, scouring floods) factors. Five of these springs were classified as undisturbed, 14 slightly, 42 moderately, and 45 as highly disturbed. Physicochemical characteristics of each spring were quantitatively (e.g., water depth, wetted width, current velocity, discharge, etc.) and qualitatively (percent bank and emergent cover, substrate composition, etc.) measured or estimated. Water chemistry (nutrients and major ions) was sampled at 19 of these springs, and the influence of disturbance on the food quality of aquatic organisms was examined through stoichiometric analysis of gastropods in 26 springs.

Examining physical characteristics of the environment, canonical correspondence analysis found that the structure of BMI communities was first related to the level of disturbance then to water temperature, spring elevation, discharge, spring brook length (a function of discharge), and spring brook bank vegetation coverage. The level of disturbance and concentration of most nutrients were correlated, but water temperature and chloride concentration were the only statistically significant chemical variables structuring communities. Stoichiometric analysis indicated that gastropod food quality was negatively affected in springs associated with non-native ungulate use.

Non-metric Multidimensional Scaling (NMDS) and Analysis of Similarity (ANOSIM) showed a weak relationship between hydrogeology and BMI communities that has been observed for reference Great Basin springs. This may be attributed to the overwhelming influence of disturbance on the ecology of these Nevada springs. Thermal (>30^{o}C) and cool (<30^{o}C) springs were analyzed separately because of differences in their BMI communities. Characteristics of BMI communities in cool and thermal springs generally varied along a gradient of increasing disturbance. Differences between disturbance categories and BMI communities in thermal springs were statistically significant for moderately and highly disturbed springs, but not for slightly disturbed sites (no undisturbed, thermal springs were sampled). Differences between the structure of BMI communities were also statistically significant between all disturbance categories, with exception when undisturbed and slightly disturbed sites were compared. Differences between BMI communities in highly disturbed springs that were affected by ungulates, diversion, recreation, drying, or scouring floods were not statistically significant. Statistically significant differences between disturbance categories were observed for 23 of the 28 bioassessment metrics calculated for cool springs, and for 2 of 28 metrics for thermal springs, which indicates that bioassessment may be weakly applied to thermal springs. NMDS and ANOSIM of cool spring BMIs showed there was little difference between results examining their structure or bioassessment. In thermal springs, however, differences were best shown by examining community structure, and bioassessment was minimally informative.

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LIST OF ACRONYMS

ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
BMIs	Benthic Macroinvertebrates
CCA	Canonical Correspondence Analysis
DIN	Total Inorganic Nitrogen
DM	Dry Mass
EC	Electrical Conductance
HBI	Hilsenhoff Biotic Index
NMDS	Non-Metric Multidimensional Scaling
rRNA	Ribosomal RNA
TP	Total Phosphorus

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INTRODUCTION

Springs are small aquatic systems that occur where groundwater reaches the surface (Meinzer 1923). 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. Arid land 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, and diverse lithology (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 (in review) examined hydrogeology and ecology of reference Great Basin and Mojave Desert springs and found that the characteristics of benthic macroinvertebrate (BMI) communities were correlated 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 1997, Myers and Resh 1999). As a consequence of their lengthy isolation and long-term persistence, many Great Basin 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, springs are generally more stable than lotic systems because they are not exposed to wide seasonal 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 much of this work has been in deserts and focused on crenophile taxonomy and biogeography (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, Anderson and Anderson 1995), 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 condition of desert springs degraded 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), and there has been little attention given to understanding the effects of human disturbance on spring ecology or factors affecting their ecological health (Sada et al. 2001, 2005).

Several studies provide insight into the response of spring-fed communities to varying levels of human activity. Sada et al. (2005) and Fleishman et al. (2006) found that benthic macroinvertebrate (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 three classes of springs. They identified reference, moderately and, severely disturbed springs, and found taxonomic richness was highest in severely disturbed springs, dipterans increased with disturbance, and they calculated metric scores for each class of spring. In a stoichiometric assessment of spring-dwelling gastropods, Mehler et al. (draft) found that body size was inversely correlated with water temperature and nitrate (NO_3-N) concentration, but no studies have examined the relationship between human disturbance and gastropod stoichiometry.

These studies suggest that spring-fed aquatic and riparian communities may be resistant to minor disturbance, but that communities are affected by higher levels of disturbance. This is consistent with a basic tenant of ecological processes whereby the effects of disturbance on a system is a function of its magnitude, duration, and frequency. Ecological systems are characteristically resistant and resilient to low magnitude disturbances that are short term and infrequent, but they may be functionally altered when a disturbance is frequent, long lasting, or exceedingly large (see Picket and White 1985).

Nevada is the driest and most mountainous state, and springs are its highest priority wetlands (Skudlarek 2006). The Nevada Natural Heritage Program is currently preparing a State Wetland Program Plan (WPP) to guide the management and protection of these resources. This work on springs supports the WPP by providing methods to assess the ecological health of spring-fed wetlands and guide the public, and State and Federal agencies to create programs whereby these resources can be used without compromising their ecological health.

In this study we examined relationships between disturbance by examining physicochemical environments, gastropod stoichiometry, and benthic macroinvertebrates (BMI) communities. BMI communities were quantitatively sampled to assess the efficacy of applying a qualitative assessment of disturbance to examine the ecological health of spring systems. These communities were studied because their structure indicates ecological heath of aquatic systems, and they rapidly respond to environmental change in other lotic and lentic systems throughout the world (e.g., Rosenberg and Resh 1983. Barbour et al. 1999). We sampled BMIs and spring brook environments at reference valley floor, bajada, and geothermal springs that were identified by Sada and Thomas (in review), and at randomly selected springs categorized as being undisturbed, slightly, moderately, or highly disturbed during 2012 and 2013 field studies. Additionally, we examined gastropod stoichiometry. Stoichiometry theory is based on the premise that herbivores often face nutritional challenges due to the gross chemical imbalances between the food they eat and their body (tissue) (Sterner and Elser 2002). Growth of aquatic herbivores is generally determined by the availability and quality of food (Acharya et al. 2004), in addition to several abiotic factors (such as temperature and pH). Additionally, anthropogenic disturbances can modify the temporal and spatial distribution of key elemental ratios containing elements such as carbon (C), nitrogen (N), and phosphorus (P) and in turn affect material flow and nutrient cycling through food webs (e.g., Sterner and Elser 2002, Cross et al. 2006). We examined gastropod stoichiometry determine relationships between nutrients, disturbance, and food quality for a single group of aquatic organisms (gastropods) that often numerically dominate BMI communities in springs.

Relationships between the structure and functional characteristics of BMI communities were examined to: 1-Provide insight into the effect of human disturbance on the ecological health desert springs, 2-Determine the efficacy of a qualitative assessment to gain insight into the ecological health of desert springs, 3-Determine if the biological effects of disturbance differ between different classes of springs (e.g., cool and thermal springs), 4-examine differential effects of natural and human disturbance on BMI communities, and 5-examine the relationship between disturbance an food quality. Understanding relationships between disturbance and ecological health is critical to assessing the effects of human use and natural events on springs, and to guide their management and restoration.

BASIC SPRING ECOLOGY

It is important to understand basic elements of spring ecology to understand the design of these studies and their results.

Springs support relatively small aquatic and riparian communities in desert regions. Their small size suggests that they are ‘simple’ ecological systems with low environmental and biological diversity. While this is believed to be true when compared to larger systems in more mesic regions, they discharge over all aspects of the desert landscape (mountains, valleys, bajadas, etc.), and their diversity in water chemistry that is a function of aquifer geology, residence time, etc., (e.g., Garside and Schilling 1979, Thomas et al. 1996), and morphology (e.g., 12 ‘spheres’ of discharge reported by Springer and Stevens 2009) suggest that individual springs may be relatively ‘simple’ but that they are environmentally and ecologically diverse across the landscape (Springer et al. 2008).

There have been few ecological studies of BMI communities in desert springs, and most of these have examined undisturbed springs, and have been limited to single sites (e.g., Blinn

2008, Meffe and Marsh 1983, Sada and Herbst 2006). These studies found BMI communities were structured by habitat characteristics (e.g., water velocity, temperature, substrate composition, water temperature, and environmental variability) that change along a continuum from the spring source to the spring brook terminus where water either evaporates, infiltrates into the ground, or enters a larger aquatic ecosystem (Meffe and Marsh 1983, Heyford et al. 1995, Sada and Herbst 2006). Communities near spring sources differ from mid-spring brook communities, and communities near the disappearance of water at the spring brook terminus (e.g., Lindegaard et al. 1998, McCabe 1998). Communities near spring sources are typically comprised of taxa that are relatively intolerant of harsh environments, and they change along a gradient where downstream BMI taxa are increasingly tolerant of harsh conditions (increasing maxima and temporal variability in temperature, dissolved oxygen concentration, pH, etc.) in lower spring brook reaches.

Benthic communities near spring sources may also be affected by its morphology. Taxa in rheocrene springs are more likely to be adapted to flowing environments, whereas taxa in limnocrenes and helocrenes are more adapted to ponded or marshland habitats (see Appendix A for a Glossary of Terms).

In the only landscape assessment of reference condition, rheocrene Great Basin and Mojave Desert, springs Sada and Thomas (in review) found that factors related to hydrogeology (e.g., temperature, EC, etc.) were more important to structuring BMI communities than were physical characteristics of the environment (e.g., discharge, substrate, elevation, water depth, current velocity, etc.). From sampling 52 springs they also found that structural and functional characteristics of BMI communities in these reference springs can be predicted by determining aquifer provenance, landscape association, and groundwater flow pathways. In this region, different communities occupied regional aquifer and geothermal springs, and springs located in mountains, on bajadas and valley floors, and springs associated with playas. These observations suggest that biological criteria characterizing reference condition for springs that discharge from each of these aquifers and flow pathways are distinct, and mutually exclusive. This strongly suggests that a unique set of spring system reference characteristics must be determined in context of hydrogeology and landscape setting rather than physical characteristics of the spring environment.

METHODS

SITE SELECTION

During 2012 and 2013, 114 springs were randomly selected from a database of records describing the physical, chemical, and disturbance characteristics of approximately 1,500 Great Basin and Mojave Desert springs (Figure 1, Appendix B). Most of these springs are isolated and

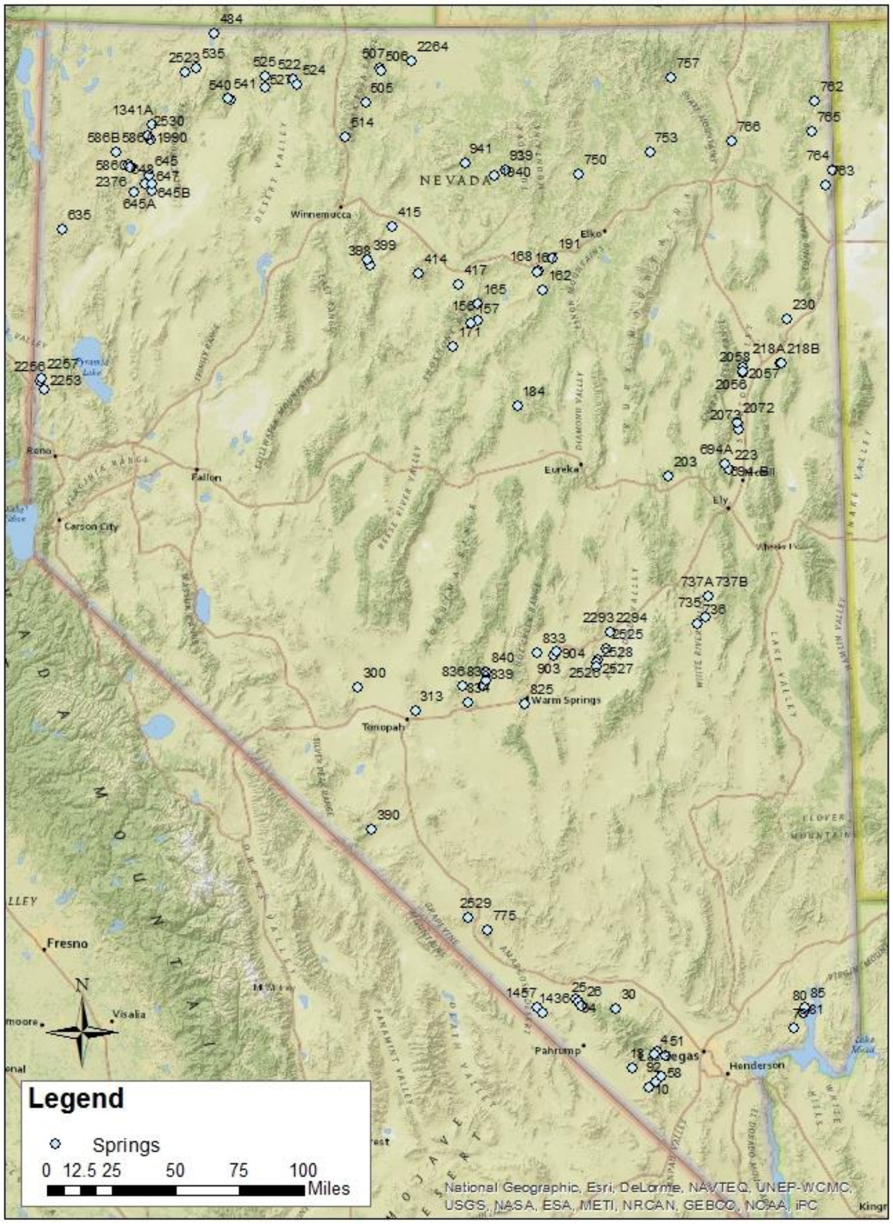

Figure 1. The location and identification numbers of springs sampled in 2012 and 2013. See Appendix B for information identifying the location and environmental characteristics for each spring.

their spring brooks dry before they reach other aquatic systems. These records have been compiled since the early 1990s and include a qualitative assessment that categorizes the level and type of human (livestock, diversion, recreation) and natural (scouring floods and drying) disturbance of each spring as undisturbed, slightly, moderately, and highly disturbed. It is not possible determine if a spring has been altered by historical human activity, but the absence of evidence of recent disturbance suggests that if it had been disturbed, its environmental and biological characteristics may have naturalized to pre-disturbance conditions. These disturbance categories are based on work by Sada and Nachlinger (1998) in southern Nevada, and described in Sada and Pohlmann (2006) (see Appendix C for a description of disturbance categories) and they are one component of U.S. National Park Service inventories of approximately 3,000 springs in the Mojave, Sonoran Desert, and Chihuahuan Desert Networks of National Parks (Sada and Pohlmann 2007, Sada and Jacobs 2008 a, b, c; Sada 2013 a, b). Characteristics of these BMI communities are compared with 11east central California (Owens Valley) and eight northwestern and northeastern Nevada (Ruby Valley, Soldier Meadow, Railroad Valley) reference bajada, valley floor, and geothermal springs as examined by Sada and Thomas (in review).

FIELD METHODS

Aquatic habitat metrics and BMIs were collected once during summer months, and sampling was limited to the upper 25 m of spring brook where environments are most stable.

Spring Environments

Sixteen estimated and measured environmental metrics were recorded in the upper 25 m of each spring brook when BMIs were collected (Table 1). More detailed water chemistry was examined with laboratory analysis of water collected from the source of 19 springs in southern Nevada to determine the relationship of 15 chemical constituents on the structure of BMI communities (Table 2, Appendix B). The location and elevation of each spring were recorded using a Garmin Map 60C GPS unit. Water chemistry was measured in spring sources. Temperature and EC were measured using a YSI Model 30 meter. Mean water column velocity was measured using a Marsh-McBirney Model 2000 meter, and pH using an Oakton pHTestr 2 meter that was calibrated daily. Discharge was estimated by calculating the mean volume of water captured per unit of time during three samples in a 113 L (30 gallon) plastic bag (discharge was estimated when it exceeded 500 L/minute). Wetted width was calculated as the mean width of five evenly-space transects that were oriented perpendicular to the thalweg. Water depth and current velocity were calculated from measurements made at the center of quadrats where BMIs

Table 1. Physicochemical metrics that were measured (bold) and estimated in springs and spring brooks to examine the relationship between BMI communities and disturbance in Great Basin and Mojave Desert Springs. Disturbance categories based on Sada and Pohlmann (2006) and described Appendix C. Aquifer Association also described in Appendix C.

Metric	Units
Elevation	Meters
Disturbance	Categorical: 1 = Undisturbed, 2 = Slight, 3 = Moderate, 4 = High
Water temperature	^{o}C
Electrical Conductance (EC)	µmhos
pH	
Mean Water Depth	Centimeters
Mean Wetted Width	Centimeters
Mean Water Column Velocity	Centimeters/second
Discharge	Liters/Minute
Spring Brook Length	Meters
Emergent Vegetation	Estimated Proportion Covered
Bank Vegetation Cover	Estimated Proportion Covered
Substrate	Mean Particle Size
Source Morphology	Rheocrene, Limnocrene, Helocrene, Unknown
Stubble Height	Estimated Centimeters
Aquifer Association	Regional, Mountain, Valley, Bajada, or Thermal

were sampled, and spring brook length was the distance from the spring source to the terminus of surface water, or to confluence with a stream. Substrate composition was estimated as the proportional composition of substrate sizes in the upper 25 m of spring brook following a Wentworth Particle Scale (Wentworth 1922). Disturbance was evaluated by guidance described in Sada and Pohlmann (2006), and aquifer associations were determined following guidelines in Sada and Thomas (in review).

Benthic Macroinvertebrates

BMI samples were collected using a 500µ net and compositing 5 samples collected within 120 cm^2 quadrats placed within the upper 25 m of spring brooks. Quadrats were placed along five transects, that were placed at 5 m intervals, and oriented perpendicular to the thalweg.

Quadrats were sequentially placed along transects at spring brook center, right bank, center, left bank, and center.

Table 2. Water chemistry constituents measured at 19 springs during 2012 and 2013 surveys to determine relationships between the structure of BMI communities and water chemistry (See Appendix C). Water samples collected from spring sources, and from springs in southern Nevada.

Calcium (Ca)	Orthophosphate (O-PO_4-P)	pH
Chloride (Cl)	Total Phosphate (TP)	EC (µS/cm)
Sodium (Na)	Nitrate-Nitrogen (NO_3-N)	Magnesium (Mg)
Potassium (K)	Nitrite (NO_{2}-N)	Silicate (SiO_2)
Sulfide (SO_4)	Ammonia-Nitrogen (NH_3-N)	Bicarbonate (HCO_3)

Collections were made by roiling the substrate within quadrats to release BMIs and allow them to drift downstream into the net. Samples were preserved in 90 percent ethyl alcohol and returned to the DRI Aquatic Ecology Laboratory for processing. Owens Valley and Ruby Valley were composited samples collected in the upper 25 m of spring brook using a 500µ mesh D-frame net. All individuals collected in these samples were identified and enumerated (as reported in Sada et al. [2000] and Sada and Herbst [2006]).

Gastropod Stoichiometry

Gastropods, water temperature, pH, EC, and water samples were measured or collected near the source of 26 springs during 2012 and 2013. These samples were not collected at the same time as other physicochemical and BMI sampling. Temperature, pH, and EC were measured using a YSI-model 650 NMDS temperature-oxygen meter. Water samples were collected in 0.5 L, acid-washed plastic bottle and snails were collected by gently brushing from rocks and submerged macrophytes. Gastropods were sorted and identified to the lowest possible taxonomic level (to species for springsnails and *Melanoides tuberculata*, and the genus *Physa*) in the field. Algae (the potential food source) from each spring was collected by scraping from submerged substrate and vegetation. All samples were placed on dry ice and shipped to the laboratory within 24 hours, where they were dried at 50°C for 72 hours before processing.

LABORATORY METHODS

Benthic Macroinvertebrates

BMIs were sorted from debris by trained technicians using a microscope (~10x). A total of 300 individuals were randomly selected, identified, and enumerated. Vinson and Hawkins (1996) found that enumerating 300 BMIs in a sample is adequate to quantify its community structure. Insects and gastropods were identified to genus. Flatworms were identified to order, roundworms and nematodes to phylum, ostracodes to class, and annelid worms to family.

Gastropod Stoichiometry

Taxa were identified to species in the laboratory following macroscopic examination. A total of 16 species were identified in four genera (6 *Pyrgulopsis* spp., 2 *Tryonia* sp., *Physa* sp., and *M. tuberculata* [non-native]). After drying, dry mass of each snail was weighed and its shell length (distance between the tip of the apex and the edge of the bottom lip) measured with calipers to the nearest 0.01 mm. Tissue was removed from shells, and this tissue and algae were ground to a fine powder using a mortar and pestle before analysis. At least 200 µg of tissue for each species was used to determine phosphorus (P), carbon (C), and nitrogen (N) content in algae and snail tissue from each spring. The tissue of small snails were pooled to achieve the necessary mass, and larger snails (e.g., *Physa* sp., *M. tuberculata*) were analyzed individually. Water samples were analyzed for total phosphorus (TP) and total inorganic nitrogen (DIN) at the Desert Research Institute (Reno) Water Analysis Laboratory according to APHA (1992) standards. P was analyzed using the ascorbic acid method by digesting samples in potassium persulfate and sulfuric acid for 1 h at 121°C, and P concentration was determined with a spectrophotometer (UV PharmaSpec-1700, UV-VIS spectrophotometer, Shimadzu, Columbia, MD, USA). Apple leaves were used as a standard reference (1515 Apple Leaves, National Institute of Standards and Technology, US Department of Commerce). C and N were analyzed by dry combustion at 960°C using an elemental analyzer (Perkin-Elmer 2400 Series II CHNS/O Analyzer, Waltham, MA, USA) at Goldwater Environmental Laboratory, Arizona State University. C, N, and P concentrations were calculated as percentage per dry mass (DM), and C:N, C:P, and N:P ratios were calculated based on molar units. Carbon, nitrogen, and phosphorus content in algae and snails were expressed in percent of dry mass and elemental ratios expressed on a molar base.

Data Analysis

Benthic Macroinvertebrate Communities

Relationships between spring environments, disturbance, and structure and functional characteristics of BMI communities were examined using multivariate analysis (Canonical Correspondence Analysis [CCA], Non-Metric Multidimensional Scaling [NMDS], and Analysis of Similarity [ANOSIM]). CCA examined the relationship between the structure of BMI communities and environmental variables shown in Table 1. This is a direct gradient analysis that is an incomplete assessment of these relationships (e.g., ter Braak and Verdonschot 1995), but it provides insight into the relative contribution of the tested environmental variables in structuring communities. All of the other multivariate analyses included reference springs from Owens and Ruby Valleys and focused on the relationship between the structure and functional characteristics of BMI communities and the a priori assignment of each spring to a disturbance category. To reduce the influence of rare taxa on the results of multivariate analysis only taxa that occurred in more than 90 percent of the springs were included (N = 86).

NMDS was calculated using a Bray-Curtis resemblance matrix with 250 starts and 0.01 minimum stress. This procedure calculates and plots 2-d and 3-d scores that illustrate similarities and differences between groups of data sets. Similar data groups are clustered with one another, and dissimilar groups are indicated by either the absence of clustering or the distance between clusters. This analysis calculates a stress value that `indicates the degree of dimensionality to the data. Very low values (< 0.05) indicate strong dimensionality, low values (0.1) indicate good dimensionality, moderate values (< 0.20) indicate weak dimensionality, and values > 0.30 indicate the absence of dimensionality.

Analysis of similarity (ANOSIM) is an *a priori* assessment examining the relationship between community characteristics and predetermined groups (ergo disturbance levels) of samples (ergo communities). It tests the null hypothesis that there are no differences between groups and calculates global and pair-wise (between groups) R values that are a test statistics that is centered around zero. Values near zero indicate similar resemblance within and among groups (hence no difference between groups), and higher values indicate dissimilarity between groups (Clarke and Gorley 2006). This was calculated using a Bray-Curtis matrix and 999 permutations.

Gastropod Stoichiometry

Elemental imbalances between gastropods (snails) and their food were calculated for each spring as shown in Elser and Hassett (1994):

$$X{:}Y_{Imbalance} = X{:}Y_{Producer} - X{:}Y_{Consumer} \qquad (1)$$

where $X{:}Y_{Imbalance}$ is the elemental producer - consumer imbalance, $X{:}Y_{Producer}$ is the elemental ratio of the producer (i.e., algae) and $X{:}Y_{Consumer}$ is the elemental ratio of the consumer (i.e., gastropods). When $X{:}Y_{Producer} > X{:}Y_{Consumer}$,the imbalances are positive. The potential N:P recycling ratio for each snail taxa was calculated by using the stoichiometric model of Elser and Urabe (1999):

$$s = f/(1-L) - bL(1-L), \qquad \text{when f > b} \qquad (2)$$

$$s = f(1-L)/(1-Lf/b), \qquad \text{when f} \leq \text{b} \qquad (3)$$

where s is the nutrient ratio released by the consumer, f is the N:P ratio of the producer, b is the N:P ratio of the consumer, and L is the maximum assimilation efficiency for the limiting nutrient. Assimilation efficiencies were assumed to be 0.75 for all calculations according to Sterner and Hessen (1994) for aquatic herbivores.

Snail tissue and algae C, N, P, C:N, C:P, and N:P data were tested for normality and homogeneity of variances before statistical analyses using the Shapiro-Wilks and Levene tests, respectively, and log-transformed if necessary. Analysis of variance (ANOVA) was used to test for differences in snail body size between warm and cold springs. ANOVA was used to test for differences in algae and snail's %C, %N, %P, C:N, C:P, and N:P between warm and cold springs. We tested for differences in producer-consumer C:N, C:P, and N:P elemental imbalances and the potential N:P recycling ratios between warm and cold springs by using ANOVA. All statistical analyses were done in SAS version 8.2 for windows. By using linear regression we tested whether water temperature had an effect on %N and % P in gastropods and algae, and on gastropod C:P and N:P ratio.

Bioassessment

Bioassessment is a methodology that is used to evaluate ecosystem health by examining the composition of an aquatic community in context of the tolerance of its taxa to environmental harshness (e.g., Rosenberg and Resh 1993). Environments that are stressed by pollution or other harsh conditions (ergo ‘unhealthy’) support communities comprised of taxa that are tolerant of stress, and communities in benign environments (ergo ‘healthy’) are comprised mostly of intolerant species. Bioassessment metrics are calculated by examining all organisms, or different taxonomic, lifestyle, and behavioral assemblages, within a BMI community (see Rosenberg and Resh 1993; Barbour et al., 1999). Taxonomic richness and Hilsenhoff Biotic Index (HBI) (Hilsenhoff 1987) are two metrics that consider the entire BMI community. Generally, the number of taxa in a community (richness) is lower in stressed or harsh environments than it is in benign and unstressed systems. HBI is an index that is calculated from values that classify the tolerance of each BMI taxon to stress and harsh environments, and it is the most commonly used as a sediment and pollution tolerance metric (Hilsenhoff 1987, Relyea et al., 2000). Taxa with high values are tolerant of stress, and taxa with low values are intolerant of stress. Concomitantly, communities with high HBI values are comprised of taxa that are tolerant of stress (ergo stressed), whereas taxa intolerant of stressful environments comprise communities with low HBI values. Metrics that consider assemblages within the BMI community include the number, and relative abundance, of intolerant and tolerant taxa, and the percent of mayflies, stoneflies, and caddisflies in a community (known as the EPT Index). Life style metrics (e.g., feeding strategies, behavior, etc.) were also calculated.

Functional characteristics of BMI communities occupying different disturbance levels were examined using 28 bioassessment metrics (Appendix E) (e.g., Barbour et al., 1999, Bailey and Norris 2004) that were calculated from all taxa that were identified and enumerated in 2012 and 2013 samples. Differences between metrics calculated for each disturbance category were tested using a Kruskal-Wallis one-way ANOVA. Differences between functional characteristics were also examined using NMDS and ANOSIM.

For each analysis, all proportional values were arcsine transformed, and other values were ln (x+1) transformed. Systat® v.13 was used for statistical analysis, Primer® v. 6.0 for NMDS and ANISOM (Clarke and Gorley 2006), and CANOCO v. 4.5 for CCA (ter Braak and P. Šmilauer 2002).

RESULTS

A total of 114 springs were surveyed during 2012 and 2013, including seven that were dry and five where BMIs were absent from samples. Environment/BMI relationships were examined in 103 springs (dry springs and springs without BMIs were excluded from this analysis). Aquifer associations of these springs included 23 valley floor, 37 bajada, 15 geothermal, 34 mountain, and four regional springs as classified by Sada and Thomas (in review). Of the 108 flowing springs, five appeared to be undisturbed by natural (e.g., drying, scouring by floods, etc.) or human factors, and four were categorized as undisturbed, 14 as slightly, 42 moderately, and 45 as highly disturbed (environmental characteristics of each spring are shown in Appendix B, and photographs showing representative springs affected by different disturbance levels are shown in Appendix F). Non-native ungulates (livestock and horses) disturbed most springs, and many were affected by several anthropogenic and natural factors (Table 3). Differences in the structure of BMI communities and bioassessment metrics in the different disturbance categories were examined for springs sampled in 2012 and 2013, and compared to reference valley floor, bajada, geothermal, and regional springs in Nevada and eastern California as described by Sada and Thomas (in review). Additionally, the different disturbance categories were examined are compared to 19 additional springs from the Owens Valley, CA and Ruby Valley and northwestern NV that Sada and Thomas (in review) identified as reference springs. Sixty-four of the springs were rheocrenes, 11 limnocrenes, 28 helocrenes, and the hypocrenes, unknown, and cave seeps were unusual (Appendix B). Thirteen springs were thermal (temperature > 30^{o}C).

Benthic communities sampled in 2012 and 2013 were determined by examining 46,420 organisms (mean/spring = 354.4, range = 30 to 1,418). Samples included a total of 201 taxa (mean/spring = 14.1, range = 3 to 33). All of these taxa were included in the bioassessment analysis. Of these, 86 occurred in > 10 percent of the springs and were used in the multivariate analyses (Appendix G).

Seven genera were the most abundant organisms in undisturbed, slight, moderate, and highly disturbed cool and thermal springs sampled in 2012 and 2013 (Table 4). These included taxa with relatively low and relatively high tolerance values (values ranged from 3 to 10). The

Table 3. The number of springs categorized as slightly, moderately, and highly disturbed in 2012 and 2013 spring surveys. Most moderately and highly disturbed springs were affected by ungulates, and many were disturbed by one or more additional factors (e.g., ungulates plus diversion, flooding, or recreation). Four springs were undisturbed.

Slight		**Moderate**		**High**	
Ungulates	Recreation	Ungulates	Multiple	Ungulates	Multiple
14	3	43	20	46	29

Table 4. The percentage of the three most abundant taxa in undisturbed, slight, moderate, and highly disturbed springs sampled in 2012 and 2013. Tolerance value shown in parentheses.

Cool Springs	**Most Abundant**	**2nd Most Abundant**	**3rd Most Abundant**
Undisturbed(n=3)	Ostracoda-31.7 (8)	Oribatei—22.1 (5)	*Pyrgulopsis*-13.6 (4)
Slight(n=9)	*Hyallela*-23.8 (4)	*Pyrgulopsis*-23.6 (4)	Ostracoda-12.9 (8)
Moderate(n=38)	Ostracoda-39.4 (8)	Nematoda-14.6 (6)	*Hyallela*-11.5 (4)
Highly(n=35)	Ostracoda-33.5 (8)	Nematoda-12.4 (6)	Tubificidae-6.8 (10)
Thermal Springs	**Most Abundant**	**2nd Most Abundant**	**3rd Most Abundant**
Undisturbed(n=2)	*Pyrgulopsis*-43.6 (4)	*Hyallela*-26.6 (4)	*Microcylloepus*-15.7 (4)
Slight(n=4)	*Pyrgulopsis*-36.4 (4)	Ostracoda-25.8 (8)	*Hyallela*-5.9 (4)
Moderate(n=5)	Ostracoda-29.4 (8)	*Hyallela*-23.8 (4)	*Culiciodes*-6.6 (6)
Highly(n=3)	*Culiciodes*-22.7 (6)	Nematoda-15.5 (6)	Ostracoda-(8)

numeric dominance of taxa occupying cool (temperatures < 30^{o}C) and thermal springs in context of disturbance generally followed a pattern where taxa with lower tolerance values dominated the least disturbed springs. Conversely, taxa with higher tolerance dominated communities that were moderately and highly disturbed. The pattern in undisturbed, cool springs differed from this with Ostracodes (tolerance value = 8) dominating the community. Reasons for this exception are unknown, but they may be attributed to the small number (n = 3) of undisturbed cool springs that were sampled.

SPRING ENVIRONMENT/BMI COMMUNITY RELATIONSHIPS

Physicochemical Environment

Canonical correspondence analysis was used to examine relationships between: 1-16 spring brook metrics describing physicochemical characteristics of the environment (and three important, basic hydrogeology metrics [EC, temperature, and pH] (see Table 1) and 2-15 water chemistry constituents (see Table 2). Both analyses used 86 BMI taxa describing community structure.

Manual forward selection analyzing physicochemical metrics found six environmental variables were statistically significant ($p < 0.05$), including disturbance ($p = 0.002$), temperature ($p = 0.002$), percent bank cover ($p = 0.002$), elevation ($p = 0.016$), discharge ($p = 0.022$), and spring brook length ($p = 0.046$). Total inertia of the analysis using only these statistically significant variables was 3.145, and 78.8 percent of the species- environment correlation was explained in the first two axes (Table 5).

A CCA plot of the analysis examining only the statistically significant environmental variables shows that the importance of disturbance, water temperature, and elevation to structuring the BMI community are nearly equivalent, disturbance is orthogonal to these factors (Figure 2). Temperature and elevation are inversely correlated, with higher temperatures occurring at lower elevation. Discharge, spring brook length, and bank vegetation coverage are inversely associated with disturbance, which indicates that vegetation coverage is less at more highly disturbed sites, and that the influence of disturbance on communities differs between small and larger springs. The importance of temperature shown by this analysis is consistent with Sada and Thomas (in review) who found that BMI communities in thermal (geothermal and regional aquifer springs) and cool springs differed. Taxa in thermal springs were more tolerant of harsh conditions than taxa in cool springs.

Water Chemistry

Manual forward selection in the Canonical Correspondence Analysis of BMI communities and water chemistry constituents found only two statistically significant ($p < 0.05$) variables, including water temperature ($p = 0.002$) and chloride ($p = 0.032$). Total inertia of the analysis using all variables was 3.456 (Table 6). Axis 1 explained more than 99 percent of the species-environment correlations, but cumulative variance of species data and species-

Table 5. Canonical Correspondence Analysis summary relating physicochemical characteristics of spring brook environments and BMI community structure in springs sampled in 2012 and 2013.

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.141	0.123	0.067	0.049
Species-Environment Correlations	0.770	0.788	0.714	0.645
Cumulative Percentage Variance of Species Data	4.5	8.4	10.5	12.0
Cumulative Percentage Variance of Species-Environment Correlation	32.7	61.3	76.8	88.0
Sum of All Eigenvalues	3.145			

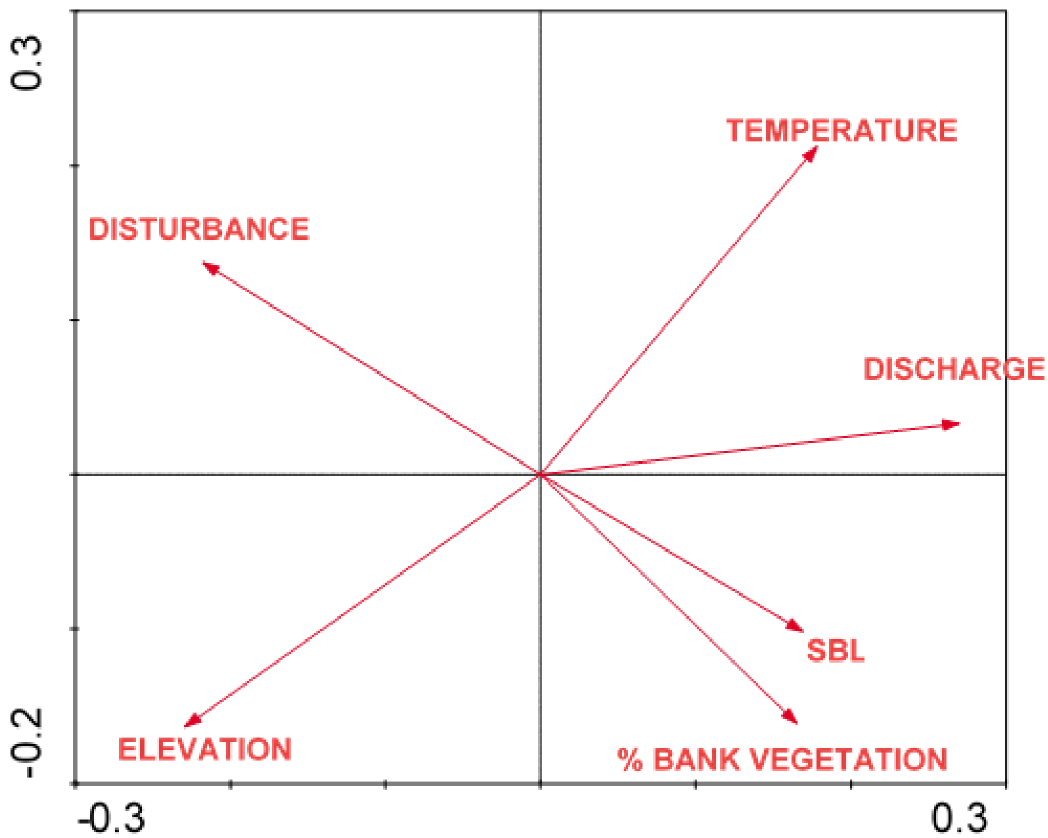

Figure 2. Canonical Correspondence Analysis plot showing the relative importance of statistically significant environmental variables to structuring BMI communities sampled in 2012 and 2013. The relative importance of variables to structuring communities is indicated by vector length.

Table 6. Canonical correspondence analysis summary relating water chemistry constituents and BMI community structure in springs sampled in 2012 and 2013.

	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**
Eigenvalues*	0.529	0.454	0.329	0.291
Species-Environment Correlations	0.996	0.999	0.969	0.900
Cumulative Percentage Variance of Species Data	15.3	28.4	37.9	46.3
Cumulative Percentage Variance of Species-Environment Correlation	16.2	30.2	40.2	49.2
Sum of All Eigenvalues	3.456			

environment correlations were low, and the first two canonical axes were not statistically significant ($p > 0.54$). This analysis suggests that relationships between BMI communities and this broad spectrum of water chemistry are weak.

The CCA biplot from this analysis illustrates the importance of temperature and chloride in structuring BMI communities, and that most variation in the BMI/water chemistry relationship is explained on Axis 1 (Figure 3). Temperature and chloride are correlated with one another, and with most other major ions that were sampled (HCO_3 was the exception). Disturbance levels and nutrient concentrations are separate from, and generally orthogonal, to the relationship with major ions, and concentration of most nutrients were correlated with higher disturbance (DIST). Interestingly, concentration of nitrate-nitrogen (NO_3-N) and disturbance were inversely correlated. Although this CCA indicated that nutrient concentrations had no statistically significant effect on BMI communities, their association with disturbance suggests that their effects are more associated with disturbance than with the influence of most major ions.

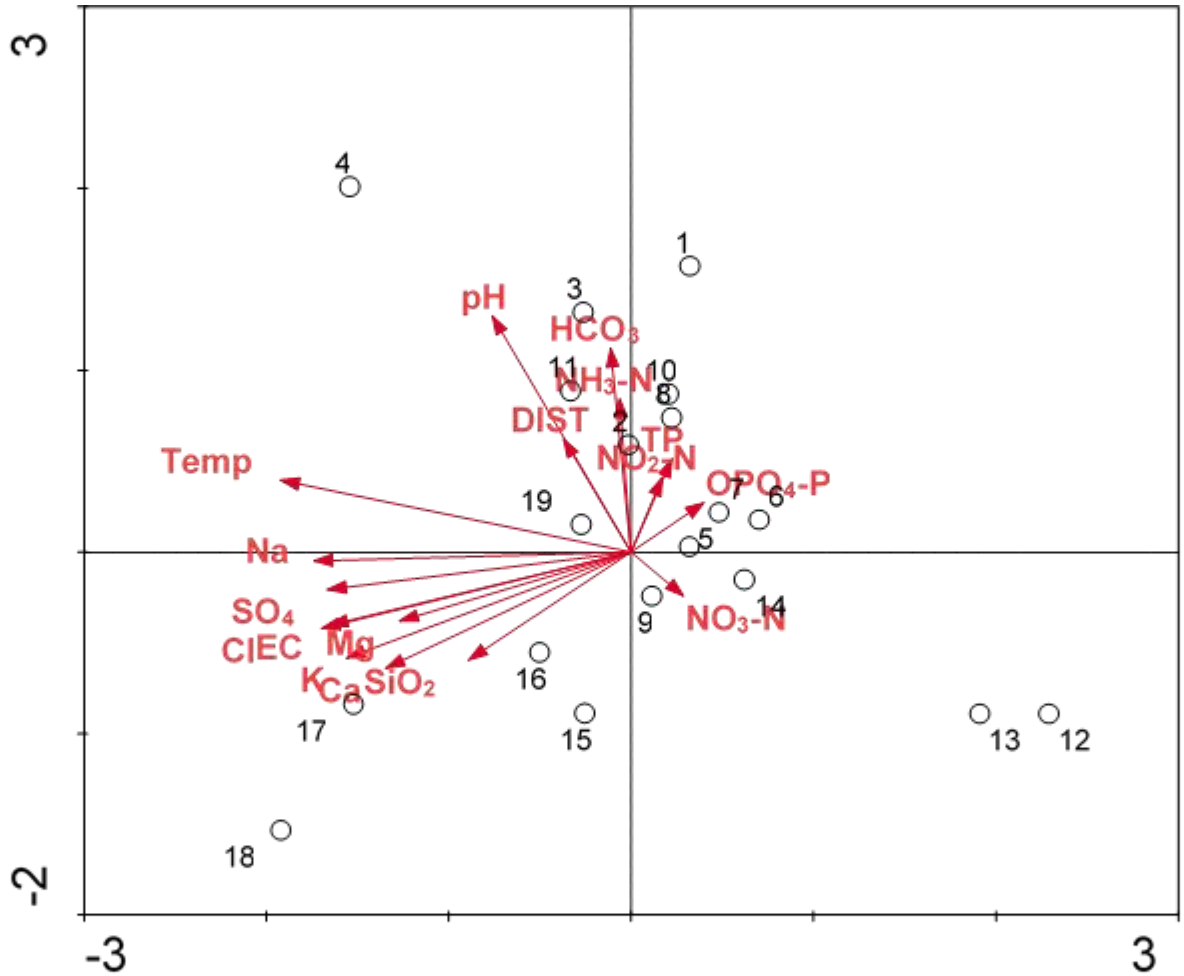

Figure 3. Canonical correspondence analysis biplot showing the relationship between water chemistry and structure of BMI communities. Temperature (T) and chloride (CL) were the only statistically significant constituents. Site ID numbers shown in black (See Appendix B) and abbreviations for water chemistry shown in Table 2).

The relationship between BMIs sampled in 2012 and 2013 and BMI/aquifer associations that were identified by Sada and Thomas (in review) were examined using NMDS and ANOSIM. Dimensionality calculated by NMDS was high (2D Stress = 0.22) (Figure 4), and clustering as shown by ANOSIM was low (Global R = 0.065) and statistically significant between only some clusters (Table 7). Although differences between some clusters (e.g., between regional and most other aquifers and geothermal and valley aquifers), the weak and dimensionality and low Global R indicate that there is a weak relationships between aquifers and BMI communities in these springs. These observations are consistent with results from CCA showing there was minimal influence of water chemistry and physical characteristics of the environment on BMI communities sampled in 2012 and 2013 (e.g., Figures 2 and 3), but contrary to observations by Sada and Thomas (in review) and studies in other springs systems that the structure of BMI communities is influenced by hydrogeology (ergo geology, water chemistry, aquifer characteristics) (e.g., Ferrington 1995, Botosaneau 1998). Reasons that

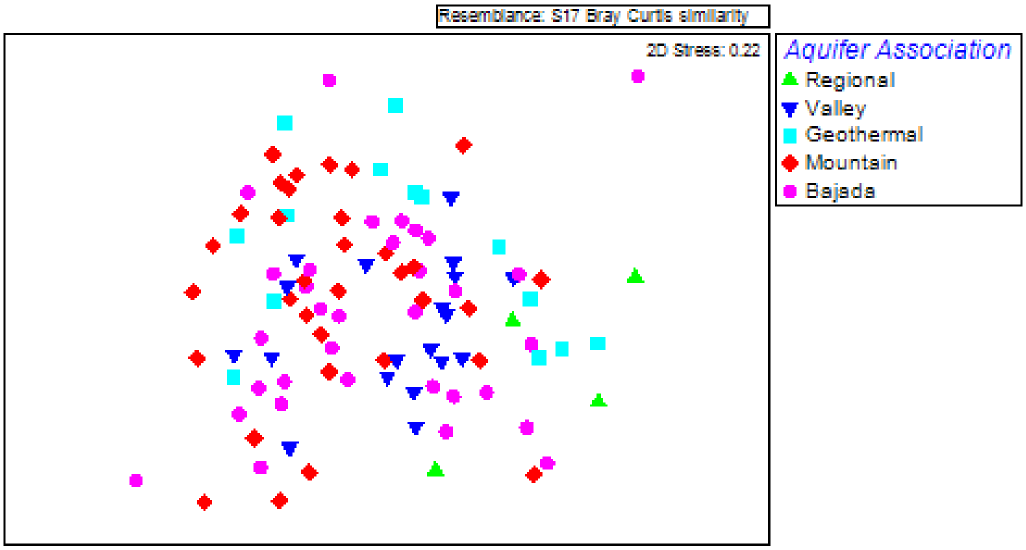

Figure 4. NMDS plot showing the association between the structure of BMI communities and aquifers in springs sampled in 2012 and 2013. ANOSIM Global R = 0.065, and the significance level of the sample statistic = 0.016.

Table 7. Results of ANOSIM analysis examining the relationship between the structure of BMI communities and aquifer associations identified by Sada and Thomas (in review). Global R = 0.073, significance level of sample statistic = 0.012.

Groups	R Statistic	p
Regional, Valley	**0.416**	**0.003**
Regional, Geothermal	0.305	0.097
Regional, Mountain	**0.337**	**0.001**
Regional, Bajada	0.144	0.052
Valley, Geothermal	**0.304**	**0.005**
Valley, Bajada	-0.119	0.995
Valley, Mountain	0.018	0.224
Geothermal, Mountain	**0.103**	**0.049**
Geothermal, Bajada	0.083	0.163
Mountain, Bajada	0.034	0.067

water chemistry has a weak influence are unclear, but the statistically significant influence of disturbance on these communities shown by CCA (see narrative associated with Table 5) suggests that its influence may overwhelm the effects of water chemistry on disturbed systems.

DISTURBANCE AND BMI COMMUNITY RELATIONSHIPS

Non-Metric Multidimensional Scaling and Analysis of Similarity

Several different sets of BMI data were used to examine relationships between the qualitatively assigned levels of disturbance and community structure. Data from all springs was examined first. Second, thermal springs were separated and efficacy of qualitative disturbance levels were examined separately for cool and thermal (> 30°C) springs. Third, analysis was limited to cool, rheocrene springs to gain insight into how the assessment may be influenced by spring source morphology.

The NMDS analysis examining the structure of BMI communities in reference valley floor, bajada, and thermal springs, and all flowing springs sampled in 2012 and 2013 showed reference springs and 2012 and 2013 springs were clustered separately (Figure 5). Reference springs were clustered to the right, and many slightly and undisturbed springs were more closely associated with these clusters than with more highly disturbed springs. Many of the moderately

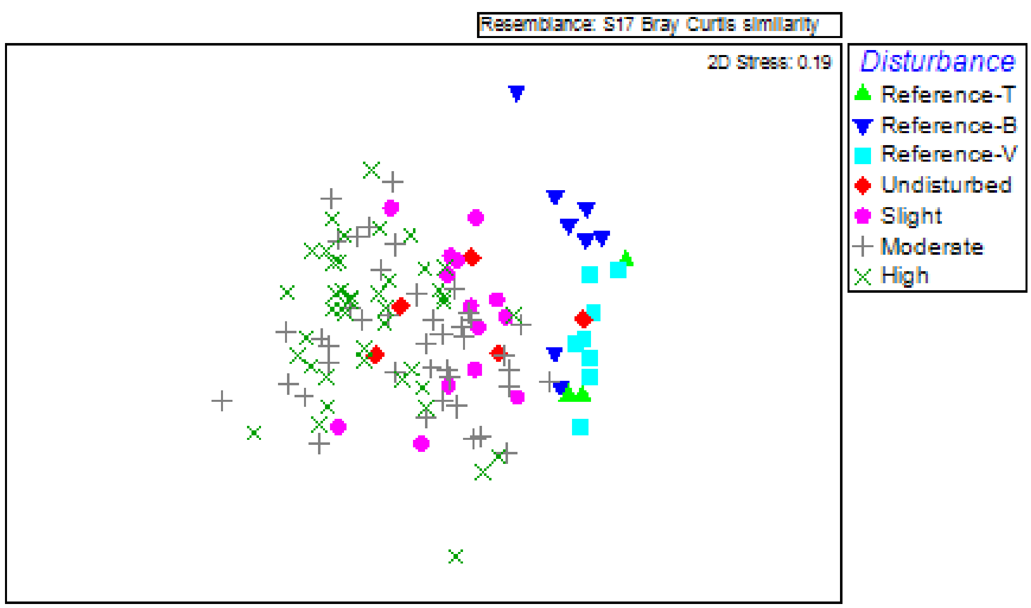

Figure 5. NMDS plot of reference BMI communities in thermal, valley floor, and bajada springs as described in Sada and Thomas (in review), and all springs sampled in 2012 and 2013 that were categorized by disturbance level.

and highly disturbed springs were distantly associated on the left, but many were also scattered close to slightly and undisturbed springs. 2D stress of the analysis was 0.19, which suggests low dimensionality and that community similarities are comparatively weak.

The Global R sample statistic calculated by ANOSIM for this set of springs was relatively small (0.297), which also indicates weak and diffuse clustering, even though its significance level was < 0.001 (Table 8). Even with the absence of strong clustering, the difference between most reference valley floor, bajada, and thermal springs were statistically significant, which is consistent with indications shown by the NMDS plot. R Statistics for these comparisons ranged from 0.325 to 0.784, which indicates that clustering of these communities is relatively tight (Table 8). Differences between reference springs and disturbance categories assigned to springs sampled 2012 and 2013 were mostly significant, which indicates that communities in reference and disturbed springs differed. However, differences between several disturbance categories assigned to springs sampled in 2012 and 2013 were not statistically significant. For example, Undisturbed springs were not different from Slightly, Moderately, or Highly disturbed springs. Differences between Slight and Moderate and Highly disturbed springs, but the lack of consistency between inter-disturbance comparisons indicates that the structure of BMI communities is weakly associated with the qualitatively assessed different levels of disturbance. These analyses demonstrated that BMI communities in the different disturbance categories sampled in 2012 and 2013 differed from reference springs, but differences between them were comparatively small. This suggests that the *a priori* assignment of disturbance levels may have little utility. Limiting NMDS to cool springs (ergo removing 14 thermal springs) did not reduce 2D stress in the NMDS analysis, but clustering appeared to improve and Slightly and Undisturbed springs more closely associated with reference springs (Figure 6).

Table 8. ANOSIM comparing the structure of BMI communities in groups of reference valley floor (Reference-V), bajada (Reference-B), and thermal (Reference-T) springs with communities in all springs sampled in 2012 and 2013. Global R sample statistic = 0.297 and significance level of the sample statistic = <0.001. Statistically significant comparisons shown in bold.

Groups	R Statistic	p
Reference-T, Reference-B	0.325	0.073
Reference-T, Reference-V	**0.487**	**0.012**
Reference-T, Undisturbed	0.138	0.23
Reference-T, Slight	**0.399**	**0.024**
Reference-T, Moderate	**0.473**	**0.007**
Reference-T, High	**0.776**	**0.001**
Reference-B, Reference-V	**0.406**	**0.007**
Reference-B, Undisturbed	**0.457**	**0.005**
Reference-B, Slight	**0.451**	**0.001**
Reference-B, Moderate	**0.639**	**0.001**
Reference-B, High	**0.784**	**0.001**
Reference-V, Undisturbed	**0.537**	**0.001**
Reference-V, Slight	**0.498**	**0.001**
Reference-V, Moderate	**0.519**	**0.001**
Reference-V, High	**0.773**	**0.001**
Undisturbed, Slight	-0.051	0.59
Undisturbed, Moderate	0.008	0.48
Undisturbed, High	0.243	0.06
Slight, Moderate	0.025	0.35
Slight, High	**0.255**	**0.001**
Moderate, High	**0.096**	**0.001**

This improved clustering was confirmed by ANOSIM (Table 9). The Global R for cool springs was 0.318 (significance level = 0.001), higher than when thermal springs were included, and indicating moderate clustering. Differences between most clusters were statistically significant except for comparison of Reference-Bajada and Undisturbed 2012 and 2013 springs, and between Slightly and Undisturbed 2012 and 2013 springs. R statistics for most of the statistically significant comparisons exceeded 0.300, indicating that clustering was relatively tight. There are several reasons for higher resolution of clusters with the removal of thermal springs from the analysis. High temperature that characterizes thermal springs is limiting for many aquatic species (e.g., Ward 1992), which suggests that taxa in thermal springs are adapted to harsh environments that are more similar to harsh environments caused by disturbance than they are to the relatively benign environments in cool springs. There may also be a greater diversity in their water chemistry due to the effect of high temperature on the solubility of many constituents.

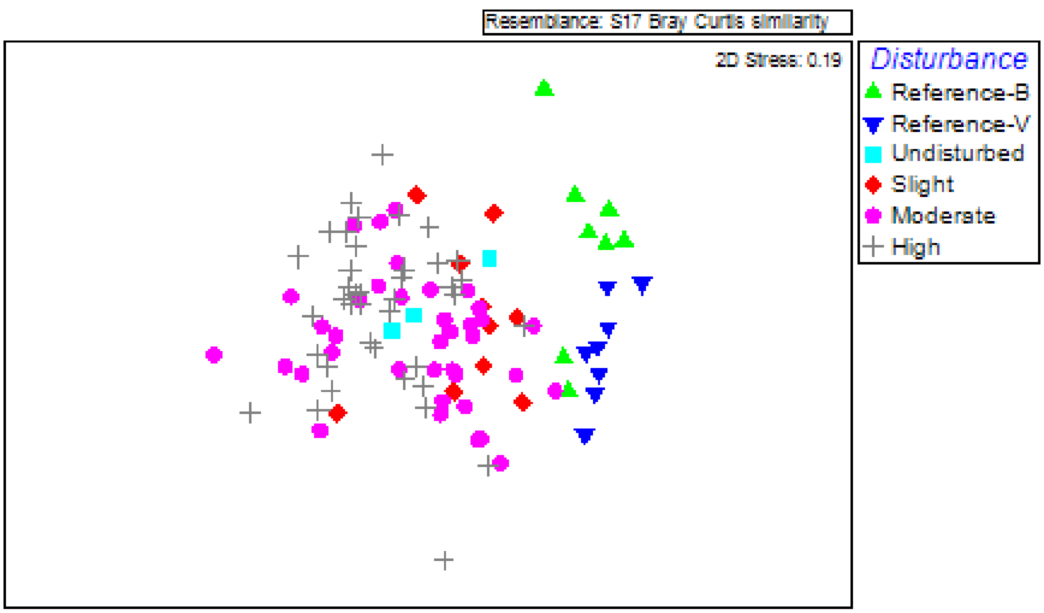

Figure 6. NMDS plot of reference BMI communities in cool valley floor, and bajada springs as described in Sada and Thomas (in review), and springs sampled in 2013 and 2013 that were categorized by disturbance level.

Table 9. ANOSIM comparing the structure of BMI communities in groups of reference valley floor (Reference-V) and bajada (Reference-B) springs with communities in disturbed springs. Analyses include all cool springs (N = 90) and only rheocrene cool springs (N = 55) to assess the possible differential effect of spring source morphology on results. Global R sample statistic = 0.1% for each analysis. Global R for all cool springs = 0.318 and for rheocrene cool springs = 0.323. Statistically significant comparisons shown in bold.

	All Cool Springs		Only Rheocrene Cool Springs	
Groups	**R Statistic**	**p**	**R Statistic**	**p**
Reference-B, Reference-V	**0.507**	**0.002**	**0.406**	**0.004**
Reference-B, Undisturbed	0.282	0.056		
Reference-B, Slight	**0.275**	**0.014**	**0.426**	**0.001**
Reference-B, Moderate	**0.768**	**.0001**	**0.611**	**0.001**
Reference-B, High	**0.816**	**.0001**	0.719	**0.001**
Reference-V, Undisturbed	**0.307**	**0.038**		
Reference-V, Slight	**0.258**	**0.022**	**0.634**	**0.001**
Reference-V, Moderate	**0.174**	**0.034**	**0.536**	**0.001**
Reference-V, High	**0.387**	**0.001**	**0.732**	**0.001**
Undisturbed, Slight	-0.123	0.805		
Undisturbed, Moderate	**0.332**	**0.019**		
Undisturbed, High	**0.353**	**0.019**		
Slight, Moderate	**0.353**	**0.008**	-0.017	0.542
Slight, High	**0.451**	**0.001**	**0.228**	**0.024**
Moderate, High	**0.087**	**0.002**	0.098	1.0

Similar results were observed for ANOSIM that was limited to cool, rheocrene springs (see Table 9). The Global R for this analysis was 0.323, which was slightly greater than for the analysis of all cool springs, and the Global R sample statistic was 0.001. Differences between Reference-Bajada and Moderately Disturbed 2012 and 2013 springs, and between Undisturbed and Slightly Disturbed 2012 and 2013 springs were the only statistically non-significant clusters. Although R Statistics for most rheocrene comparisons were similar to those calculated for all cool springs, they were consistently less than observed for cool springs. This indicates that differences between clusters of cool, rheocrene springs was less than observed for all cool springs, and that the efficacy of the qualitative assessment of disturbance may be minimally influenced by spring morphology. It may also indicate that the effect of disturbance on the structure on BMI communities may overwhelm the influence of morphology.

Thermal springs were analyzed by NMDS and ANOSIM by categorizing by disturbance level and as either geothermal or regional springs (the two types of thermal springs that occur in the Great Basin and Mojave Deserts) following Sada and Thomas (in review). The NMDS analysis showed that there was a broad distribution of BMI communities in these springs, but that there was a higher level of clustering than observed from analysis of either all springs or for cool springs. The 2D stress level was 0.0 (Figure 7). Reference geothermal and thermal springs were tightly clustered, and all of the other springs were widely distributed. Undisturbed regional springs were associated with the lower portions of the plot, but these were mixed with all disturbance levels of geothermal springs. The ANOSIM analysis generally confirmed weak clustering shown by NMDS (Table 10). The Global R Statistic was high (0.865), most R Statistics comparing disturbance groups were also high (> 0.679), and only the difference between reference and slightly disturbed Geothermal springs were not statistically significant.

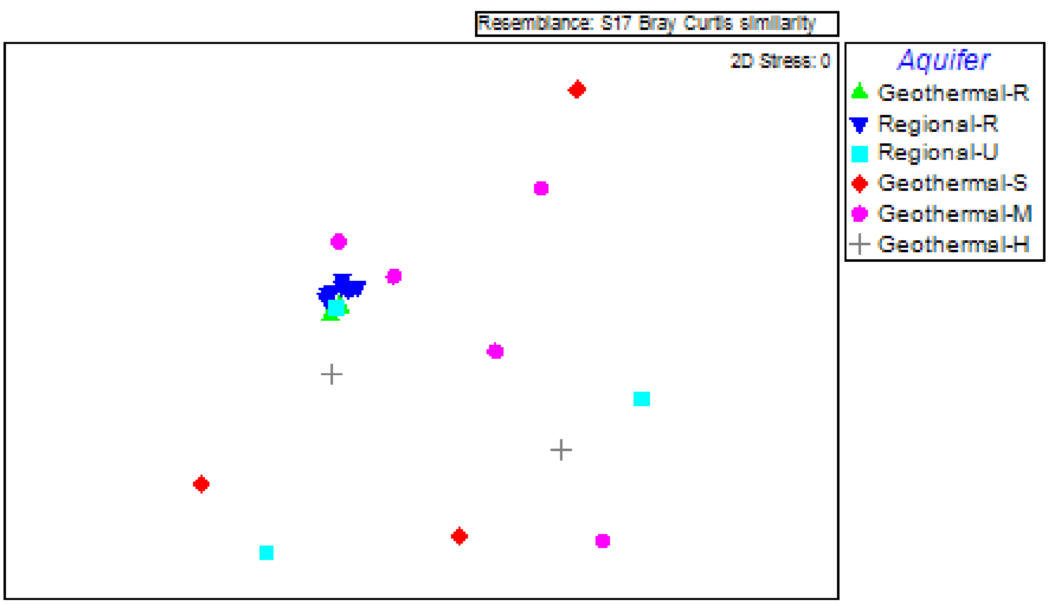

Figure 7. NMDS plot of reference BMI communities in Reference Regional and Geothermal thermal springs as described in Sada and Thomas (in review), and Geothermal and Reference thermal springs sampled in 2012 and 2013 and categorized by disturbance level.

Table 10. ANOSIM comparing the structure of BMI communities in Reference Regional (Regional-R) and Reference Geothermal (Geothermal-R). Global R sample statistic = 0.865, and significance level of sample statistic, p = 0.001. –R = Reference Geothermal and Regional springs. –U, -S, -M, and –H = undisturbed, slight, moderate, high disturbance categories.

Groups	R Statistic	p
Geothermal-R, Regional-R	**0.679**	**0.005**
Geothermal-R, Geothermal-S	1	0.10
Geothermal-R, Geothermal-M	**1**	**0.018**
Geothermal-R, Geothermal-H	**1**	**0.005**
Regional-R, Regional-U	**0.832**	**0.005**

For the ANOSIM analysis, a full set of comparisons was not possible. Only two regional, slightly disturbed springs were sampled in 2012 and 2013, and too few geothermal springs were sampled to compare differences between these springs sampled in 2012 and 2013.

The Differential Influence of Disturbance Types on BMI Communities

Differential effects of the different types of disturbance on BMI communities were examined by focusing on highly disturbed springs. This was the most common of the disturbance levels recorded and therefore provides the largest number of springs to analyze. Most of these springs were disturbed by human factors (e.g., ungulates, diversion) and some by natural factors (e.g., drying, flooding, fire). Ungulates (primarily livestock, and some horses) affected most of these springs, and there was evidence of two types of disturbance at many springs. Relatively few springs were affected by natural factors. NMDS analysis showed there was a wide diversity of BMI communities that occupied this set of springs, and dimensionality of the data was relatively high (0.19) (Figure 8). The ANISOM confirmed this with a low Global R (0.133) and high significance level of the sample statistic (p = 0.105). The only statistically significant groups were Ungulates vs. Ungulates, Flood (p >0.140 for all other comparisons). Both of these analyses suggest that there may be little ecological difference between the effects of human and natural disturbances on spring systems. Similarities between springs affected only by flooding and those affected by ungulates and drying suggest that the combined effect of ungulates and

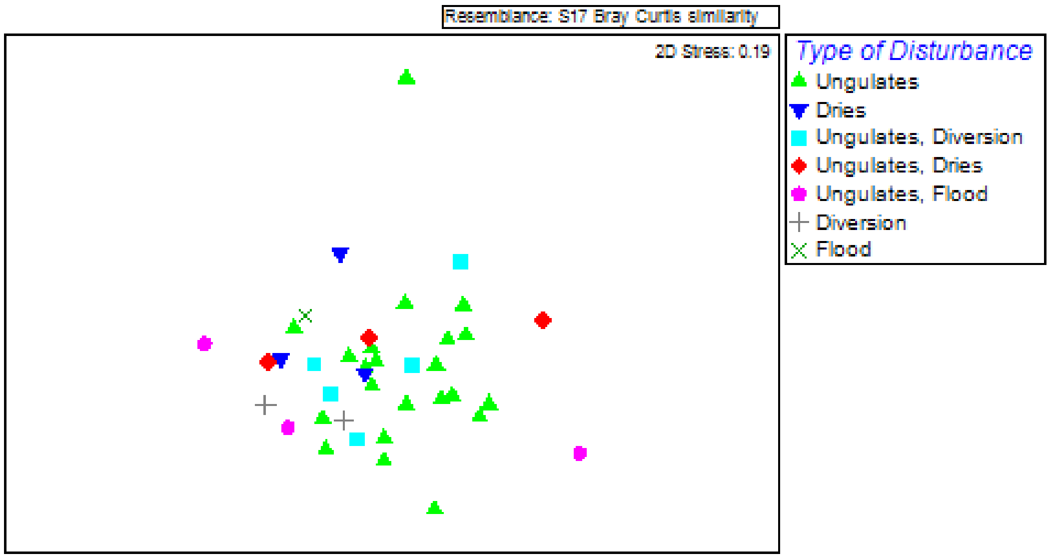

Figure 8. NMDS plot of BMI community structure in highly disturbed, cool springs sampled in 2012 and 2013. ANOSIM showed there was no statistically significant clustering for any combination of Type of Disturbance pairs (Global R = 0.133, Significance level of sample statistic p = 0.105. Only statistically significant groups are Ungulates vs. Ungulates, Flood, p > 0.140 for all other comparisons.

flooding is not distinct. The ANOSIM found no statistically significant difference between groups associated with the different types of disturbance (Figure 6).

Disturbance and Bioassessment Relationships

Bioassessment Metrics

Functional characteristics of BMI communities were assessed using 28 metrics to examine taxonomic richness, community structure, and lifestyles (Appendix E). All BMI data were used (n=201 taxa) and metrics were calculated for Reference, Undisturbed, Slightly, Moderately, and Highly disturbed springs. Following NMDS and ANOSIM results showing differential effects of disturbance on cool and thermal springs, these groups of springs were analyzed separately. Reference springs (valley floor and bajada springs) were pooled for statistical analysis of bioassessment metrics for cool springs, but separated for NMDS and ANOSIM. Differences in metrics between categories were tested using a Kruskal-Wallis one-way ANOVA non-parametric test. Data were tested for normality using a Kolmogorov-Smirnoff two-tailed test. Differences from normality were all statistically significant. Differences between disturbance categories for most cool spring bioassessment metrics springs were statistically significant (Table 11). Non-significant differences occurred only for Taxonomic and Chironomid Richness, Shannon H, Evenness, and the Percent of Intolerant EPT (Table 11). Some metrics exhibited a trend indicating effects of incrementally increasing harshness. These included the Percent of Gastropods that generally decreased with disturbance and the Percent Burrowers that generally increased. Gradients in these metrics are consistent with predictions attributed to the effects of sequentially increased disturbance (see Appendix E). Many metric values neither increased nor decreased along a sequential disturbance gradient. For instance, HBI was higher in Undisturbed than in Slightly disturbed springs, but it incrementally increased from Slight to Highly disturbed springs. Some of these discrepancies may be attributed to the relatively small number of Undisturbed and Slightly disturbed springs sampled. Unfortunately, minimally disturbed springs are rare in Nevada (Abele 2011). A number of metrics indicated that communities in Moderately disturbed springs were more tolerant of harsh conditions than communities in Highly disturbed springs. For example, EPT richness, the percent of intolerant organisms and taxa in the community were all lowest in Moderately disturbed springs. However, values for Highly disturbed springs generally indicated that harshness at these springs was greater than it was in all other disturbance categories.

In contrast to the analysis of cool springs, comparison of thermal spring disturbance categories found that only two metrics were statistically significant (Table 12). The small number may be attributed to the comparatively small number of thermal springs sampled, or to the widely varied, and relatively harsh, environments that are associated with high temperatures and solute concentrations. In contrast to cool springs, few thermal spring metrics changed along the disturbance gradient. The percent of Gastropods, Ostracods, Mites, and Scrapers declined along the disturbance gradient, and the percent of Tubificid worms, midges (Chironomidae) and Burrowers increased with the level of disturbance. It is difficult to discern if variability along the disturbance gradient is attributed to the small number of springs in each disturbance category or variability in water chemistry among these springs.

Table 11. Mean (1 standard error) bioassessment metrics for cool springs sampled in 2012 and 2013 that were undisturbed, slightly, moderately, and highly disturbed by anthropogenic and natural factors. Statistically significant differences shown in bold ($p < 0.05$, Kruskal-Wallis one-way ANOVA).

`	**Undisturbed (N=3)**	**Slight (N = 7)**	**Moderate (N = 37)**	**High (N = 43)**
Taxonomic Richness	13.7 (5.0)	17.0 (1.9)	13.4 (0.7)	14.7 (0.9)
Ephemeroptera Richness	**0.3 (0.3)**	**0.7 (0.4)**	**0.1 (0.0)**	**0.4 (0.1)**
Plecoptera Richness	**0.0(0.0)**	**0.4 (0.2)**	**0.0 (0.0)**	**0.1 (0.0)**
Trichoptera Richness	**0.3 (0.3)**	**1.2 (0.4)**	**0.3 (0.1)**	**0.3 (0.1)**
EPT Richness	**0.7 (0.7)**	**2.3 (0.7)**	**0.4 (0.1)**	**0.7 (0.2)**
Mite Richness	**1.7 (0.3)**	**1.6 (0.3)**	**0.9 (0.1)**	**0.8 (0.1)**
Chironomid Richness	4.3 (2.8)	5.4 (0.9)	4.8 (.05)	5.8 (0.6)
Shannon H	1.5 (0.3)	1.7 (0.32)	1.4 (0.1)	1.5 (0.1)
Evenness	0.6 (0.1)	0.6 (0.0)	0.6 (0.0)	0.5 (0.0)
HBI	**5.8 (0.6)**	**4.7 (0.2)**	**5.4 (0.2)**	**6.0 (0.2)**
Percent Ephemeroptera	**0.6 (0.6)**	**1.5 (0.8)**	**0.1 (0.1)**	**1.0 (0.4)**
Percent Plecoptera	**0.0 (0.0)**	**1.3 (0.9)**	**0.0 (0.0)**	**0.0 (0.0)**
Percent Trichoptera	**0.7 (0.7)**	**12.2 (5.5)**	**0.4 (0.2)**	**0.4 (0.2)**
Percent Gastropods	**13.9 (13.6)**	**18.9 (7.1)**	**11.2 (2.3)**	**7.5 (2.5)**
Percent Bivalves	**2.7 (1.4)**	**1.7 (0.8)**	**2.4 (0.6)**	**1.5 (0.4)**
Percent Ostracoda	**30.3 (18.7)**	**10.9 (3.5)**	**21.7 (4.1)**	**36.1 (4.4)**
Percent Naididae	**0.8 (0.4)**	**1.4 (1.4)**	**1.2 (0.3)**	**2.6 (0.9)**
Percent Tubificidae	**0.5 (0.5)**	**1.5 (0.5)**	**4.9 (1.7)**	**5.9 (1.3)**
Percent Intolerant EPT	**0.0 (0.0)**	**9.4 (6.2)**	**0.0 (0.0)**	**0.4 (0.2)**
Percent Tolerant EPT	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)
Percent Intolerant (community)	**0.0 (0.0)**	**9.5 (6.2)**	**0.0 (0.0)**	**0.5 (0.2)**
Percent Tolerant (community)	**34.5 (19.9)**	**17.5 (3.4)**	**31.8 (4.2)**	**49.1 (4.1)**
Percent Tolerant Taxa	**1.1 (0.2)**	**1.0 (0.1)**	**1.4 (0.2)**	**1.3 (.01)**
Percent Intolerant Taxa	**0.0 (0.0)**	**0.4 (0.1)**	**0.0 (0.0)**	**0.1 (0.0)**
Percent Shredders	**0.1 (0.1)**	**8.5 (5.4)**	**0.4 (0.2)**	**0.4 (0.2)**
Percent Scrapers	**18.8 (11.2)**	**24.9 (7.3)**	**14.4 (2.6)**	**9.1 (2.7)**
Percent Collector-Gatherers	**67.7 (11.1)**	**53.9 (8.2)**	**68.6 (3.6)**	**71.5 (3.5)**
Percent Burrowers	**2.2 (0.3)**	**4.8 (2.1)**	**12.0 (3.2)**	**17.1 (2.8)**

Table 12. Mean (1 standard error) bioassessment metrics for thermal springs sampled in 2012 and 2013 that were undisturbed, slightly, moderately, and highly disturbed by anthropogenic and natural factors. Statistically significant differences shown in bold ($p < 0.05$, Kruskal-Wallis one-way ANOVA).

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	Undisturbed/Slight (N=5)	**Moderate (N = 6)**	**High (N = 3)**
Taxonomic Richness	14.0 (3.3)	9.5 (1.8)	11.3 (2.9)
Ephemeroptera Richness	0.0 (0.0)	0.2 (0.2)	0.3 (0.3)
Plecoptera Richness	0.0(0.0)	0.0 (0.0)	0.0 (0.0)
Trichoptera Richness	0.0(0.0)	0.3 (0.3)	0.7 (0.7)
EPT Richness	0.0 (0.0)	0.5 (0.3)	1.0 (1.0)
Mite Richness	2.7 (0.3)	0.8 (0.4)	0.7 (0.3)
Chironomid Richness	1.0 (0.0)	2.2 (.07)	3.3 (1.2)
Shannon H	1.25 (0.3)	1.01 (0.3)	1.57 (0.4)
Evenness	0.53 (0.01)	0.43 (0.1)	0.64 (0.1)
HBI	5.80 (0.3)	6.44 (0.5)	5.20 (0.8)
Percent Ephemeroptera	0.0 (0.0)	0.1 (0.1)	6.6 (6.6)
Percent Plecoptera	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Percent Trichoptera	0.0 (0.0)	0.5 (0.5)	2.7 (2.7)
Percent Gastropods	**47.3 (7.5)**	**16.4 (11.4)**	**0.0 (0.0)**
Percent Bivalves	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Percent Ostracoda	33.4 (11.1)	24.0 (15.4)	13.8 (9.3)
Percent Naididae	3.0 (1.0)	4.8 (3.7)	0.6 (0.6)
Percent Tubificidae	0.9 (0.4)	0.8 (0.5)	6.2 (5.4)
Percent Intolerant EPT	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Percent Tolerant EPT	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)
Percent Intolerant (community)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)
Percent Tolerant (community)	40.8 (7.6)	53.0 (14.5)	27.13 (3.1)
Percent Tolerant Taxa	1.2 (0.0)	0.9 (0.2)	0.8 (0.1)
Percent Intolerant Taxa	0.0 (0.0)	0.0 (0.0)	0.1 (0.0)
Percent Shredders	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Percent Scrapers	**47.3 (7.5)**	**16.8 (11.8)**	**0.1 (0.1)**
Percent Collector-Gatherers	50.9 (7.9)	75.1 (11.2)	52.5 (15.2)
Percent Burrowers	9.3 (1.8)	14.9 (8.2)	32.0 (18.4)

Non-Metric Multidimensional Scaling and Analysis of Similarity

A NMDS analysis for bioassessment produces a multi-metric assessment that integrates a number of metrics to determine relationships between communities and environmental harshness (see Radar et al. 2001). Analyzing the relationship between disturbance in cool springs and statistically significant bioassessment metrics (Table 11) showed moderate clustering (2D Stress = 0.13) (Figure 9). Reference-Bajada springs were distantly separated, and Reference–Valley were slightly separated, from springs sampled in 2012 and 2013. Slightly and Moderately disturbed springs were aligned on the left side of springs while moderate and highly disturbed springs were aligned on the right and lower-left portions of the plot.

The ANOSIM analysis generally confirmed groupings indicated by NMDS (Table 13). Only differences between Reference–Bajada and Undisturbed and between Undisturbed and Slightly disturbed springs were statistically insignificant. This analysis indicates that the qualitative assessment of disturbance can be used to accurately categorize functional characteristics of the BMI community in cool springs.

Multimetric analysis of thermal spring bioassessment was inconclusive, which suggests that the qualitative assessment of disturbance using bioassessment may have little utility. It is not possible to determine if this can be attributed to the relatively small number of springs that were sampled, differences in their water chemistry, or to the possibly that human disturbance may have little effect on functional characteristics of BMI communities occupying a naturally harsh environment. The NMDS analysis indicated that clustering was comparatively strong (2D Stress = 0.12), but there were few associations relative to disturbance (Figure 10).

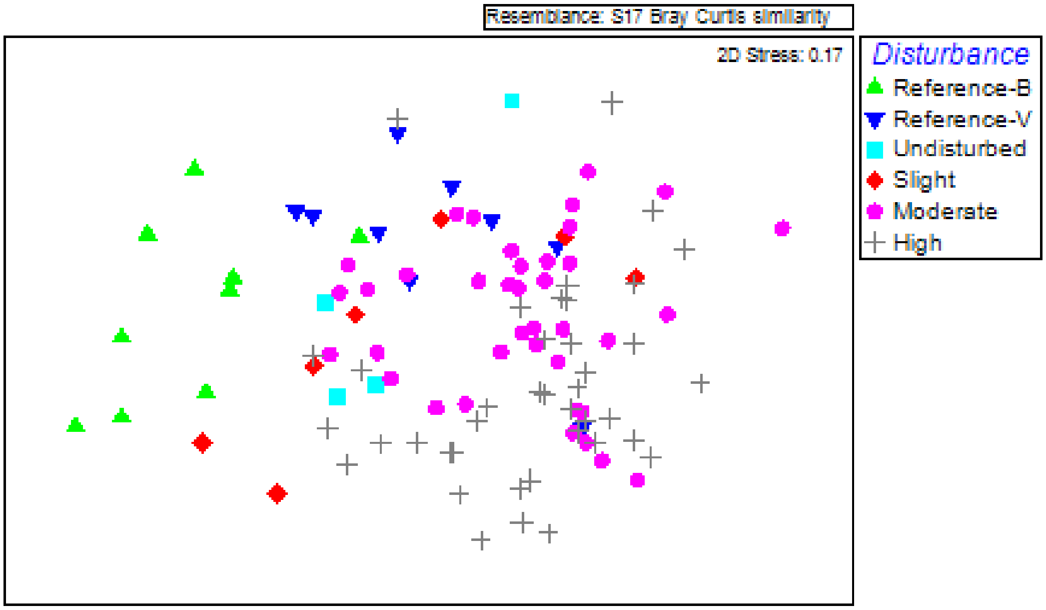

Figure 9. NMDS plot of statistically significant bioassessment metrics calculated for disturbance categories in cool springs sampled in 2012 and 2013 compared with reference valley floor (Reference-V) and bajada (Reference-B) springs described in Sada and Thomas (in review).

Table 13. ANOSIM comparing statistically significant bioassessment metrics in cool, valley floor (Reference-V), bajada (Reference-B), and springs sampled in 2012 and 2013. Global R sample statistic = 0.318 and significance level of the sample statistic = <0.001. Statistically significant comparisons shown in bold.

Groups	R Statistic	p
Reference-B, Reference-V	**0.507**	**0.001**
Reference-B, Undisturbed	0.282	0.056
Reference-B, Slight	**0.305**	**0.006**
Reference-B, Moderate	**0.764**	**0.001**
Reference-B, High	**0.816**	**0.001**
Reference-V, Undisturbed	**0.307**	**0.038**
Reference-V, Slight	**0.202**	**0.047**
Reference-V, Moderate	0.169	0.062
Reference-V, High	**0.387**	**0.001**
Undisturbed, Slight	-0.095	0.706
Undisturbed, Moderate	**0.319**	**0.021**
Undisturbed, High	**0.353**	**0.026**
Slight, Moderate	**0.299**	**0.002**
Slight, High	**0.405**	**0.002**
Moderate, High	**0.084**	**0.002**

Reference and some Moderately disturbed springs were closely aligned, while other Moderately disturbed springs were more closely aligned with Highly disturbed springs. Moderately disturbed springs were widely scattered, and sometimes closely associated with Highly disturbed springs. In contrast, Undisturbed and Slightly disturbved springs were separate and closely aligned with one another, but they were not tightly clustered.

This absence of disturbance relevant associations was confirmed by ANOSIM where differences were statistically significant for only Reference, Un/Slight and for Un/Slight, Moderate (Table 14). The R Statistic indicates that strongly different clustering for Reference and High disturbance, but they were not statistically different. This may be attributed to the small number of highly disturbed springs or to the weak clustering observed in both groups. Un/Slight springs differed considerably from other groups. This is confirmed by ANOSIM for their differences from Reference and Moderate, but not with other groups (Table 14). Differences were not statistically significant between Un/Slight and High, Reference and High.

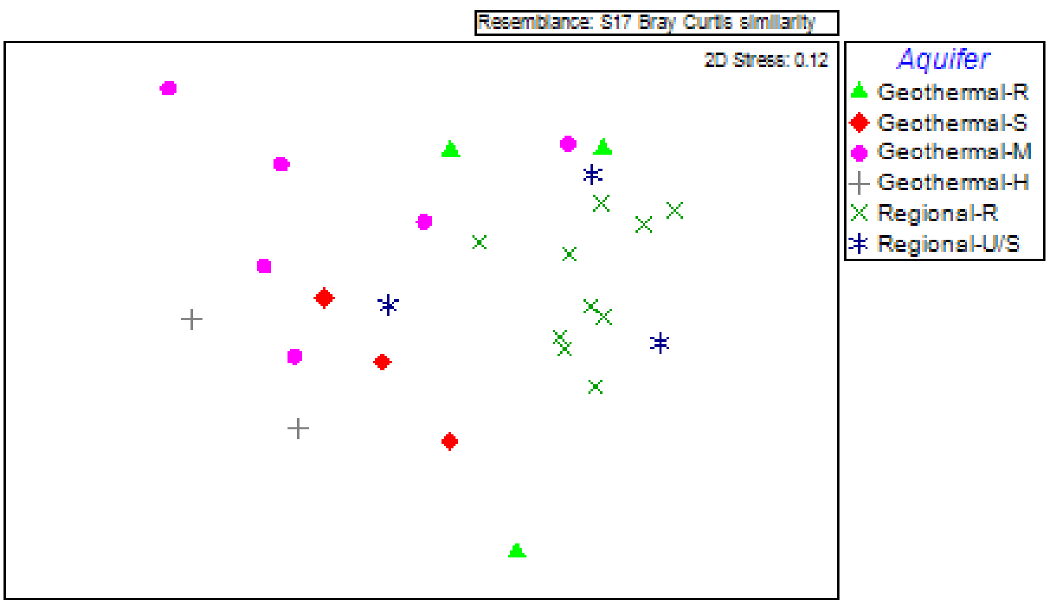

Figure 10. NMDS plot of spring bioassessment metrics (the same metrics as used for cool springs) for reference Geothermal and Regional springs, and disturbance categories for Geothermal and Regional springs sampled in 2012 and 2013. ANOSIM Global R = 0.214, only differences between reference and un/slight and un/slight and high are statistically significant ($p < 0.02$).

Table 14. ANOSIM comparing statistically significant bioassessment metrics in thermal reference and 2012 and 2013 sampled springs. Global R sample statistic = 0.571 and significance level of the sample statistic = 0.001. Statistically significant differences shown in bold.

Groups	R Statistic	p
Geothermal-R, Regional-R	**0.613**	**0.003**
Regional-R, Regional-U/S	0.333	0.08
Regional-U, Regional-S	-1	100
Geothermal-S, Geothermal-M	0.093	0.293
Geothermal-S, Geothermal-H	1	0.10
Geothermal-M, Geothermal-H	0.104	0.321

The Differential Influence of Disturbance Types on Bioassessment

Results examining the relationship between the differential influence of the type of disturbance showed that effects on BMI communities and bioassessment were similar. The NMDS analysis of bioassessment showed weak dimensionality (2D stress = 0.18) (Figure 11). The Global R sample statistic from this ANISOM was exceedingly small ($R = -0.074$) its significance level was not statistically significant ($p = 0.758$). Additionally, the significance level for all pairwise comparisons was not statistically significant ($p > 0.17$).

Gastropod Stoichiometry

Gastropods were collected from 26 springs and included 12 species of *Pyrgulopsis* (*P. merriami, P. serrata, P. turbatrix, P. marcida, P. cruciglans, P. gracilis, P. sathos, P. isolata, P. villacampae, P. papillata, P. carinata,* and *P. lockensis*), *Tryonia porrecta*, *Tryonia* sp. (undescribed from Big and Little Warm Springs), *Melanoides tuberculata* and *Physa* sp. (Table 15). *Pyrgulopsis* sp. and *Tryonia* sp. are crenophilic springsnails in the family Hydrobiidae, *Physa* sp. is a native widespread species, and *M. tuberculata* is thermophlic, native to Asia, and occupies microhabitat that is distinct from *Pyrgulopsis* spp. and *T. clathrata* (Sada 2007).

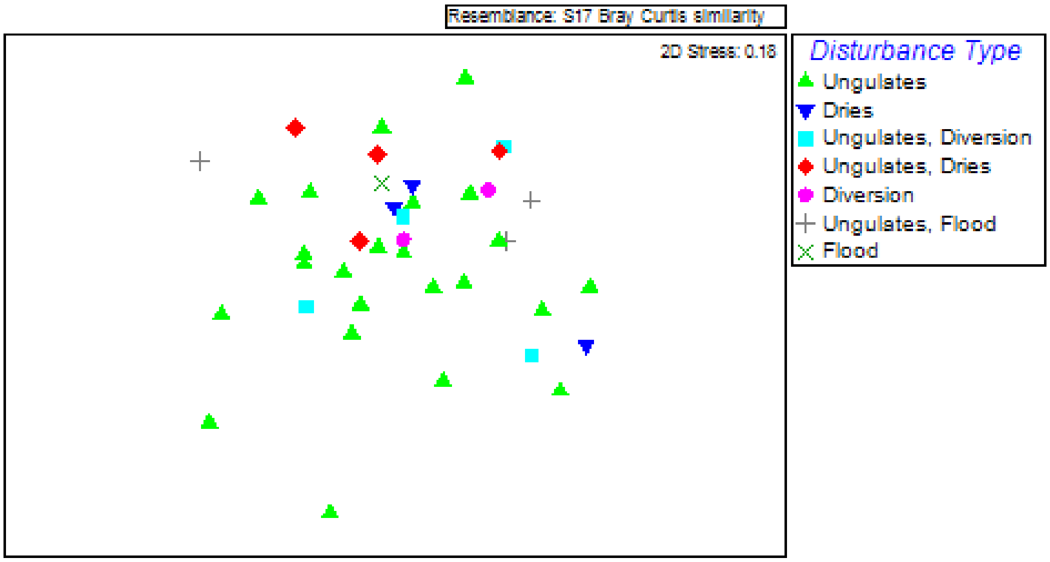

Figure 11. NMDS plot of spring bioassessment metrics (the same metrics as used for cool springs) for highly disturbed cool springs sampled in 2012 and 2013.

Stoichiometry theory is based on the premise that herbivores often face nutritional challenges due to the gross chemical imbalances between the food they eat and their body (tissue) (Sterner and Elser 2002). Growth of aquatic herbivores is generally determined by the availability and quality of food (Acharya et al. 2004), in addition to several abiotic factors (such as temperature and pH). Phosphorus is one important aspect of food quality for freshwater invertebrates (Gulati and DeMott 1997, Elser et al. 2003) and has been the focus of considerable recent study. In laboratory and field studies, *Daphnia* growth has been shown to correlate well with algal P and N content when food P and N contents are below threshold levels (Sterner et al. 1994, Acharya 2004). These studies have shown that at least some of this growth reduction is a direct result of dietary P and N deficiency. P content is considered to be an essential element to building ribosomal RNA (rRNA) and hence directly relating to organism growth rates (Ferrao-Filho et al. 2007 Elser et al. 2003) while the N content is directly linked to dietary protein supply thereby constraining growth in cases where N is in short supply (White 1993).

Table 15. Habitat characteristics and gastropod taxa sampled from 26 springs (and spring ID numbers) sampled in southern and central Nevada during 2012. Water chemistry measurements taken when gastropods were collected. ^{T} = thermal springs all other springs cool, types of disturbance indicated by superscripts: ^{D} = diversion, ^{R} recreation, ^{U} = Livestock.

Spring Name	Species	Disturbance	Temp. (°C)	EC (μS/cm)	NO_3-N (mg/L)	TP (mg/L)
Rogers (81) ^{T}	*M. tuberculata*	High^{D}	20.9	3180	0.264	0.003
Blue Point Sp. (80) ^{T}	*M. tuberculata* *T. porrecta*	Slight^{R}	30.0	3660	0.217	0.004
Calico Sp. (51)	*Physa* sp.	Moderate^{R}	24.0	650	0.003	0.007
Lost Ck. Sp. (4)	*P. turbatrix*	Slight^{R}	15.2	396	0.212	0.016
Willow Sp. (30)	*P. turbatrix*	Slight^{R}	11.2	368	0.249	0.014
Horseshootem Sp. (26)	*P. turbatrix*	High^{U}	18.5	317	1.14	0.018
Grapevine Sp. (25)	*P. turbatrix*	High^{U}	19.9	548	0.281	0.010
Indian Sp. (2529)	*Physa* sp.	Moderate^{U}	21.8	291	1.37	0.051
Sidehill Sp. (838)	*P. isolata*	Moderate^{U}	19.9	270	0.60	0.030
Reynolds Sp. West (2295B) ^{T}	*P. lockensis*	Slight^{U}	36.2	614	0.016	0.018
Reynolds Sp. East (2295A) ^{T}	*P. lockensis*	Slight^{U}	36.2	594	0.014	0.086
Hay Corral Sp. (2294) ^{T}	*P. lockensis*	Moderate^{U}	34.2	564	0.004	0.028
North Sp. (2293) ^{T}	*P. lockensis*	Slight^{U}	35.2	571	0.015	0.002
Hardy Sp. (735)	*P. marcida*	Moderate^{U}	13.9	392	1.06	0.027
Moorman Sp. (736) ^{T}	*P. merriami* *M. tuberculata* *Physa* sp.	Moderate^{U,D}	36.2	528	0.034	0.004
Emigrant Sp. (734)	*P. gracilis* *P. sathos* *P. marcida*	Moderate^{D}	17.6	469	0.76	0.042
Big Warm Sp. (881)^{T}	*P. villacampae* *P.papillata*	Moderate^{R}	30.5	681	0.02	0.012
Little Warm Sp. (882)^{T}	*P. villacampae* *P.papillata* *P. carinata* *Tryonia* sp.	Moderate^{U}	30.4	672	0.01	0.048
Bennett Sp. (223)	*P. kolobensis*	High^{U}	14.8	286	0.480	0.033
Grass A Sp. (694A)	*Pyrgulopsis* spp.	Moderate^{U}	20.6	366	0.57	0.012
Grass B Sp. (694B)	*Pyrgulopsis* spp.	Moderate^{U}	19.0	313	0.51	0.138
Cold Sp. (2073)	*P. serrata*	Moderate^{U}	10.9	420	0.55	0.038
Unnamed Sp. (2047)	*P. serrata* *Physa* sp.	Moderate^{U}	14.2	357	0.007	0.065
Unnamed Sp. (2056)	*P. serrata*	High^{U}	11.9	486	0.337	0.290
Flat A Sp. (218A)	*P. cruciglans*	High^{D}	14.4	318	1.770	0.334
Flat B Sp. (218B)	*P. cruciglans*	High^{U}	15.2	335	1.670	0.016

The interactive effects of food quality and temperature can be very important in understanding invertebrate distribution and production in springs. For species subject to short-term fluctuations in temperature (and possibly also food quality), high temperatures facilitating high somatic growth rates would pose the highest dietary demands for P (and N) in order to maximize specific growth rate, as seen in our data (Figures 12-14). Studies show that, for autotrophs, the content of P and N relative to C generally increase with increasing latitude, which is interpreted as a temperature response (Reich and Oleksyn 2004, Lovelock et al. 2007). Cold-adapted ectotherms show higher cell-specific levels of P and rRNA than individuals of the same species living under higher temperatures (Woods et al. 2003). This has been interpreted as a compensatory response to a reduced efficiency of protein synthesis at low temperatures, i.e., more ribosomes are needed to maintain a given protein synthesis rate at low temperatures.

Stoichiometric analysis suggests that C: N, C: P, and N:P ratios of pooled gastropod species were significantly ($p < 0.001$) affected by disturbance (Figures 12-14). All ratios were highest in thermal springs, which is consistent with other studies. Differences were greatest for C:P and N:P ratios in Slightly disturbed springs, which were all affected by livestock use, and nutrients added to the systems from their presence. Livestock use was also evident at two of the five Moderately disturbed springs, but other Moderately disturbed springs were altered by diversion and recreation. Lower ratios for Moderately disturbed springs may be attributed to the

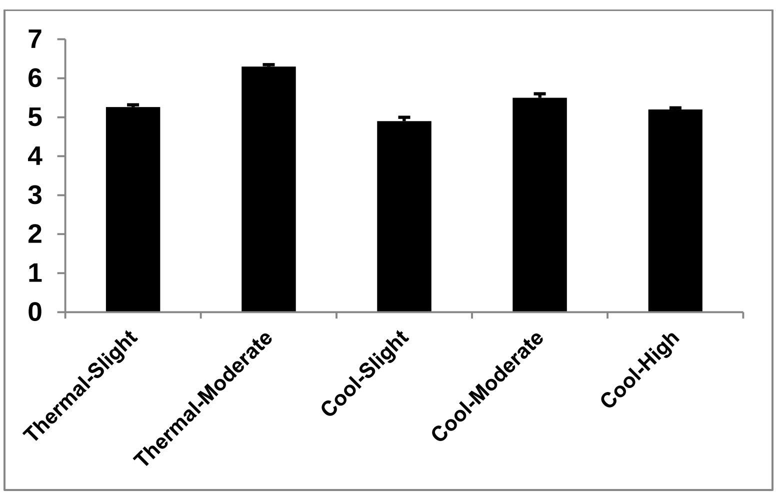

Figure 12. Mean (1 se) C:N ratios of pooled gastropods occupying thermal and cool springs as qualitatively categorized by disturbance level. No undisturbed thermal springs were sampled.

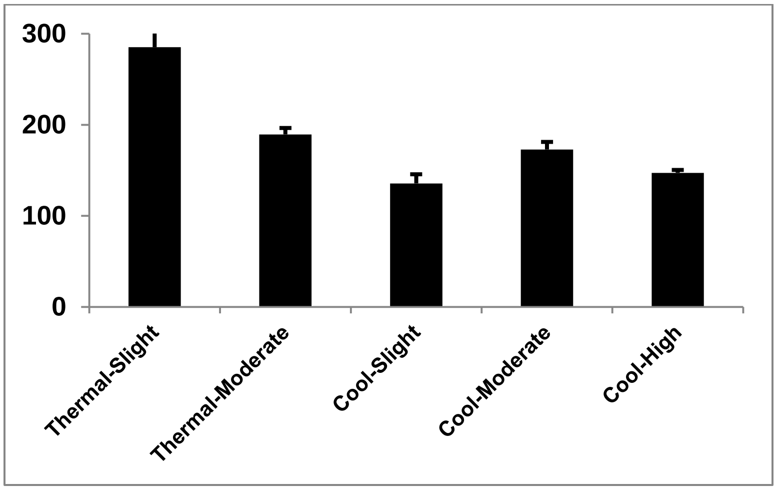

Figure 13. Mean (1 se) C:P ratios of pooled gastropods occupying thermal and cool springs as qualitatively categorized by disturbance level. No undisturbed thermal springs were sampled.

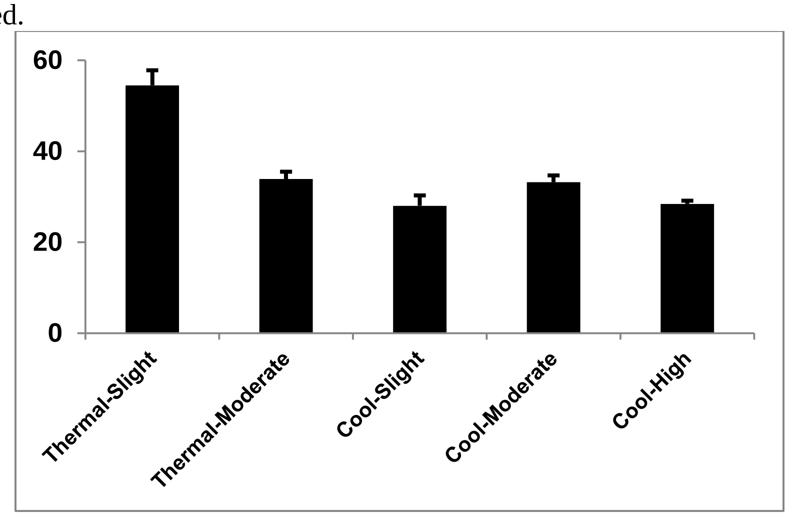

Figure 14. Mean (1 se) N:P ratios of pooled gastropods occupying thermal and cool springs as qualitatively categorized by disturbance level. No undisturbed thermal springs were sampled.

lower proportion of these springs that were affected by livestock. These comparisons suggest that different types of disturbance influence food quality, such that livestock has a greater influence on food quality than diversion and recreation. This pattern was not present in all thermal spring nutrient ratios. It is unclear why the C:N ratio in moderate springs was greater than in slightly disturbed springs.

The pattern of nutrient ratios in cool and thermal springs differed (Figures 12 – 14). In cool springs, all C:N:P ratios were lowest with slight disturbance, slightly higher with high disturbance, and highest with moderate disturbance. Of the 18 cool springs, 12 were disturbed by livestock, and six by diversion or recreation (Table 15). Slightly disturbed springs were affected only by diversion and recreation, and livestock affected seven of the nine Moderately disturbed springs and five of the seven Highly disturbed springs. Results from thermal and cool springs are consistent with stoichiometric theory regarding the effects of temperature and suggest that higher C: N: P ratios of gastropods may be due to higher nutrients attributed to from livestock grazing compared to other anthropogenic disturbances.

DISCUSSION

Many studies in aquatic systems show that BMI community composition is influenced by environmental conditions, and functional characteristics of these communities are indicative of the harshness and the ecological health of aquatic systems. (e.g., Rosenberg and Resh 1983, Barbour et al. 1999). These relationships are understood for lentic and lotic systems. However, few studies have involved spring systems, and the understanding of reference conditions and how these systems respond to human disturbance is relatively weak.

Sada and Thomas (in review) found that characteristics of BMI communities in reference Great Basin and Mojave Desert springs follow a general pattern that can be predicted by bioassessment. In these springs, harsh environments created by high temperatures and EC were dominated by tolerant organisms, and intolerant organisms characterized cool temperature and low EC springs. In their reference springs these environmental differences can be attributed to hydrogeology and the influences of geology, flowpath, and landscape setting that influence the water chemistry of springs. This suggests that it is necessary to incorporate hydrogeology when determining reference conditions for spring systems, and that reference conditions may vary as a function of hydrogeology. Some springs are naturally harsh environments and some are benign, and it is inappropriate to apply uniform standards to all types of springs. For instance, standards for cool mountain springs are not appropriate for geothermal springs. Similarly, it may be inappropriate to apply a single standard for all ‘spheres of discharge’, where there may also be differences between BMI communities in rheocrenes, helocrenes, and limnocrenes, etc..

This study examined the disturbance in a broad array of Nevada springs in context of hydrogeology, water chemistry, gastropod food quality, and the structure and functional characteristics of the BMI communities. The relationship between hydrogeology was generally weak and was indicated mostly by the influence of temperature, and by differences between communities in cool and thermal springs. A strong relationship between BMI communities and hydrolgeology would have been indicated by the strong influence of water chemistry, and aquifer provenance and flow pathways on BMI communities. Canonical correspondence analysis indicated that the importance of water chemistry and most hydrogeology factors were overwhelmed by the effects of disturbance.

The influence on the structure of BMI communities in cool and thermal springs followed a gradient of increasing disturbance that could be identified by a qualitative field assessment of each spring. This trend was also observed in bioassessment of cool springs, but not in bioassessment of thermal springs. This may be attributed to the natural tolerance of BMIs occupying thermal springs compared to cool springs, which suggests that thermal communities may be naturally more tolerant to disturbance. It also suggests that bioassessment may not be a strong tool to use in assessing the ecological integrity of these springs.

Communities in cool Nevada springs all significantly differed from reference valley floor and bajada springs, and differences between disturbance categories higher than slight were also statistically significant. Differences between the structure of communities in undisturbed and slightly disturbed cool springs were small and not statistically significant, which suggests that the ecological integrity of these springs may be minimally affected by minimal human activity or natural variability. Similar results were observed for bioassessment analysis of cool springs.

Fourteen thermal springs were sampled. Two of these were fed by regional aquifers and the remainder were geothermal. They were examined in context of reference regional and geothermal springs that were identified by Sada and Thomas (in review). Differences between the structure of communities in slightly disturbed and reference thermal springs were not significant, but differences were significant between reference geothermal, moderately, and highly disturbed springs. Differences were also significant between reference regional and undisturbed regional springs. The only undisturbed regional spring sampled in this project was in Ash Meadows and involved a spring that was restored approximately 10 years ago. It is possible that BMIs in this spring are still affected by past disturbance during restoration, and when it was diverted, dredged, and impounded for agriculture between 1966 and 1984 (Sada 1990). Bioassessment analysis of thermal springs was not informative. This may be attributed to the small number of springs that were sampled or to the inherent characteristics of BMI communities that occupy naturally harsh environments.

Although there was a relationship between characteristics of BMI communities and the severity of disturbance, an examination of highly disturbed springs indicated that communities were similarly affected by different types of natural and human disturbances. Hence, effects of ungulate use were similar to effects of drying, scouring floods, recreation, diversion, etc.

These observations compliment work by Keleher and Radar (2008b) in Bonneville Basin springs in northwestern Utah, where they quantitatively described BMI communities and measured disturbance with several metrics. There are similarities and differences between results of the two studies. Keleher and Radar (2008b) identified four ‘classes’ of springs that were generally distinguished by water temperature, pH and EC, and reference conditions for three of these classes. They found that BMIs in some springs did not respond to livestock use, and suggested that springs were adapted to prehistorical use of ungulates. It is doubtful that grazers prehistorically impacted Nevada springs. The American bison (*Bison bison*) was a dominant herbivore in central North America, but they were incidental inhabitants of Nevada. Pronghorn (*Antilocarpa americana*) and mule deer (*Odocoileus hemoinus*) occur throughout Nevada, but the life history of these native species indicates that they have little impact on riparian or aquatic systems. Their diet consists mostly forbs and browse, and little riparian vegetation. Food provides much of their water and they use springs as often secondary water sources.

Keleher and Radar (2008b) also observed that taxonomic richness and disturbance were correlated, that rare taxa increased with disturbance due to increased food availability. They also identified 12 bioassessment metrics that were used to calculate an index of biological integrity (IBI) for their springs.

Our studies found no relationship between disturbance and taxonomic richness, and that the influences of hydrogeology (with exception of water temperature) were overwhelmed by the effects of disturbance. Differences between the studies may be attributed to several factors. It appears that community composition differed between springs in the two studies. For instance, the amphipod *Gammarus lacustris* was an important species in Bonneville Basin communities, and rare in Nevada springs, where *Hyallela azteca* was the important amphipod. The midge *Microspectra* spp. was an important species distinguishing differences between communities experiencing different levels of disturbance in Bonneville Basin springs, and this genus was relatively uncommon in Nevada springs.

There may also be differences in the level or intensity of disturbance in Bonneville Basin and Nevada springs. For instance, of the 125 springs they sampled, 39 were identified as reference, which is a considerably higher proportion of undisturbed or slightly disturbed sites that we sampled in Nevada. Other spring surveys in Nevada suggest that slightly and undisturbed springs are exceedingly rare in the state (Abele 2011, DRI springs database).

In contrast to Keleher and Radar (2008b), our study found that nutrients had no significant effect on BMI communities. Gastropod stoichiometry indicated, however, that invertebrate food quality may be affected by the type of disturbance. Food quality appeared to be degraded by low and moderate levels of ungulate use, and less affected by recreation and diversion. Our studies also found weak associations between nutrients and BMIs, and stoichiometric analysis of gastropods indicated that invertebrate food quality was negatively associated with ungulate use. Differences were observed in the food quality in thermal and cool springs. Woods et al. (2003) found that there are effects of both temperature and elemental C: P ratio on growth rate, confirming interaction between the two clearly showing that temperature reaction is affected by food stoichiometry, and that the effect of dietary P limitation varies with temperature. Woods et al. (2003) further suggest that cold-acclimated poikilotherms contain on average 30–50 percent more N, P, protein, and RNA than warm-exposed conspecifics. According to Woods et al. (2003) most poikilothermic organisms are larger when they develop in or acclimate to cold temperatures, compared with conspecifics exposed to warm temperatures and this is attributed to alterations in cell size rather than number (Partridge et al. 1994). In conclusion, cold exposure leads to significant increases in nutrient content and amount in body tissues. Therefore, correlations between temperature gradient and C: N: P ratios in our data may be due to increased temperature leading to higher short term growth rates in invertebrates causing higher nutrient demands in warm springs. This may appear to be an advantage in the short term but this will eventually cause a nutrient bottleneck for these organisms leading to nutrient short supply and affecting the ecosystem and species diversity.

Mechanisms by which human activity affect spring environments and communities are probably similar to effects reported for other aquatic and riparian systems. There is little information describing the effects of ungulates on BMIs in springs. In northwestern Nevada, Sada (2015) observed that BMI communities in springs that were moderately disturbed by ungulates were comprised of tolerant species in all reaches of spring brook, and that community composition was similar from the spring source to the spring brook terminus. This contrasted with reference springs where the structure of BMI communities differed near spring sources, at mid-spring brook, and near the spring brook terminus, and BMIs near spring sources were generally less tolerant than communities in downstream reaches. These observations in reference springs were similar to findings of other studies involving undisturbed springs (see. Botosaneau 1998). The paucity of information examining the effects of ungulates indicates that additional study is needed to fully understand the effects of ungulates on BMI communities in springs. In studies in streams and rivers, Fleischiner (1994) and Kauffman and Kruger (1984) reported that livestock grazing alters thermal characteristics and increases sediment in aquatic systems through alteration or a reduction of riparian vegetation. Perla and Stevens (2008) found reduced vegetative structure (e.g., diversity of shrub, midcanopy, and tall canopy cover) and ground cover at grazed springs. Grazed springs also had greater cover by wetland grasses, sedges, and rushes. They also observed higher productivity and higher terrestrial invertebrate richness and abundance at ungrazed sites compared to grazed sites.

Few studies have examined the effects of decreased discharge on spring systems. Spring discharge in the western US has been primarily affected by surface diversion from spring sources and spring brooks and pumping that causes a decline in aquifer levels and reduced spring discharge. In extreme cases when springs and spring brooks are dried, all aquatic life is extirpated (Miller 1961, Minckley and Deacon 1968, Williams et al. 1985). Springs and spring brooks may not dry when diversions leave water in the system, but results from Sada (2015) and by Morrison et al. (2013) show that decreased discharge affects spring brook habitat and the structure and functional characteristics of the BMI community. Aquatic habitat and productivity are affected in a number of ways. As discharge is reduced, spring brook length and wetted width decrease, which affects the environment by reducing aquatic habitat volume, the area of wetted habitat, and the amount of BMI habitat and the area receiving energy from allochothonous and autochotonous sources for primary and secondary production. Decreasing the volume of water also alters thermal characteristics of the spring brook, as well as aspects of water chemistry such as pH and dissolved oxygen concentration. Consequences of these incremental changes include reduced productivity, habitat heterogeneity, and BMI microhabitat availability, which will reduce BMI abundance and affect BMI community composition and structure.

Morrison et al. (2013) found tipping points indicating substantial spring brook environmental change in wetted width and water depth occurred with less than a 20 percent decrease in discharge. The tipping point for change in water temperature occurred when discharge was decreased by approximately 30 percent, and it was approximately 40 percent for current velocity. Sada (2015) observed structural and functional changes in the BMI community in a spring moderately impacted by ungulates and where discharge was reduced by 20 percent. He also observed effects on the BMI community in springs reduced by 40 and 60 percent of their full discharge. In another study, the biological response to changing temperature of a spring was demonstrated by Hogg and Williams (1996) who examined effects of climate change on BMIs by experimentally increasing the mean annual temperature of a spring brook by 2.1°C and 2.4°C over two years. They observed decreases in animal density, biomass, and taxonomic richness, and for some species increased growth rates, smaller body size, and altered adult emergence patterns. Both of these studies indicate that substantial ecological changes occur in spring ecosystems with relatively minor decreases in discharge and increases in temperature.

Our study shows change in BMI communities along a gradient of increasing disturbance. Although it describes a method to assess the ecological condition of individual springs, and it also provides an opportunity to determine the effect of changes in land use on a spring system. By periodically sampling the BMI community, improvement or restoration of a spring would be indicated by the increasing presence of intolerant taxa and fewer tolerant organisms in the BMI community. Conversely, the adverse effect of changing use would be indicated by increasing tolerant and fewer intolerant taxa.

Keleher and Radar (2008b) observed relationships between BMIs and a quantitative assessment of disturbance. Our study showed that similar results occur with a qualitative assessment of disturbance, which suggests that disturbance need not be quantified to accurately determine characteristics of BMI communities. Using a qualitative assessment reduces survey cost and increases the ability to rapidly assess the ecological health of springs. Results of this study would be enhanced by: 1—conducting additional surveys to more accurately determine reference conditions. These conditions should be quantified in context of hydrogeology and landscape setting, as suggested by Sada and Thomas (in review). 2—determining an index of biological integrity for Nevada springs.

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APPENDIX A: GLOSSARY

Abiotic	Non-living, lifeless.
Anthropogenic	Factors caused or produced by humans or their activities.
Crenophilic	Obligate, spring associated organisms.
Crenophile	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.
Spring brook	A channel that carries water flowing from a spring.
Spring province	A group of springs in close geographical proximity.
Thalweg	A line joining the lowest portion of a stream or springbrook along gradient from source downstream.
Thermal	Warm or hot.
Thermophiles	Plants and animals that only occupy thermal habitats.
Temporal fluctuation	Fluctuations that occur over time.

APPENDIX B: LOCATION AND PHYSICOCHEMICAL CHARACTERISTICS OF NEVADA SPRINGS SAMPLED IN 2012 AND 2013

Dry springs are shown in rust color, springs with no BMIs shown yellow.

Location is of each spring source.

Units of physicochemical information as shown in Table 1.

The type (livestock, diversion, etc.) and level of disturbance is shown for each spring.

The level of disturbance for each disturbance type is categorized as: 0 = undisturbed, 1 = slight, 2 = moderate, and 3 = high.

Aquifer Association is identified as: M = mountain, V = valley floor, B = bajada, G = geothermal, R = regional

	ID #	ZONE	North	East	Twnshp	Range	SEC	State	County
Marsh Sp.	1457	11S	4031762	561854	18S	51E	Center 30	NV	Nye
Point of Rocks Sp.	1436	11S	4028727	565121	18S	51E	SE 7	NV	Nye
Unnamed Sp. Nr Lida	390	11S	4143659	456888	6S	40E	NE12	NV	ESMERELDA
Indian Sp. #2	774	11S	4088844	518264	11S	46E	SE26	NV	NYE
Specie Sp.	775	11S	4080436	530265	12S	48E	NW30	NV	NYE
Kwichup Sp.	94	11S	4036799	586135	17S	53E	NE17	NV	NYE
Grapevine Sp.	25	11S	4035104	587252	17S	53E	SW21	NV	NYE
Horseshootem Sp.	26	11S	4033141	589687	17S	53E	SE27	NV	NYE
Lost Cabin Sp.	18	11S	3994062	621258	21S	56N	NE35	NV	CLARK
Potosi Sp.	10	11S	3981676	631542	23S	57E	SE1	NV	CLARK
Potosi BSA Sp.	92	11S	3985473	635808	22N	58E	29	NV	CLARK
Mud Sp. #1	58	11S	3988434	639797	22N	58E	NE23	NV	CLARK
Calico Sp.	51	11S	4001732	641896	21S	59E	SW6	NV	CLARK
Willow Sp.	30	11S	4031086	610748	18S	55E	NE2	NV	CLARK
Willow Sp.-A	30A	11S	403098	610794	18S	55E	NE2	NV	CLARK
White Rock Sp.	3	11S	4004308	636718	20S	58E	NE34	NV	CLARK
Lost Sp.	4	11S	4002285	635084	21S	58E	NE4	NV	CLARK
Bitter Sp.	79	11S	4018542	723303	19S	67E	NW16	NV	CLARK
Blue Point Sp.	80	11S	4030200	730243	18S	68E	NE7	NV	CLARK
Rogers Sp.	81	11S	4028845	729346	18S	67E	SE12	NV	CLARK
Upper Valley of Fire Sp.	85	11S	4032236	730445	17S	68E	SW31	NV	CLARK
Crow Sp.	300	11S	4233598	448198	4N	39E	NE33	NV	ESMERELDA
Ice Plant Sp.	313	11S	4218986	484588	3N	43E	NE17	NV	NYE
Warm Sp., Monitor Range	836	11S	4234065	514865	5N	46E	SW28	NV	NYE
Mud Sp.	834	11S	4223713	517712	4N	36E	NW35	NV	NYE
Side Hill Sp.	838	11S	4234259	527145	5N	47E	NW26	NV	NYE
Point of Rocks Sp.	839	11S	4237791	528900	5N	47E	NW13	NV	NYE
Warm Sp., Monitor Range	840	11S	4243452	529435	6N	47E	SW25	NV	NYE
Black Sp.	825	11S	4222879	553837	3 1/2N	50E	NE33	NV	NYE
Iceburg Sp.	903	11S	4253568	572237	7N	52E	NW31	NV	NYE

	ID #	ZONE	North	East	Twnshp	Range	SEC	State	County
Rattlesnake Sp.	904	11S	4255989	573427	7N	52E	SE19	NV	NYE
Blue Jay Sp.	833	11S	4255690	561128	7N	50E	SW24	NV	NYE
North Sp.	2293	11S	4268714	607599	8N	55E	NE15	NV	NYE
Hay Corral Sp.	2294	11S	4268336	607671	8N	55E	NE15	NV	NYE
Reynolds Sp.-B	2295B	11S	4268060	607470	8N	55E	NE15	NV	NYE
ReynoldsSp.-A	2295A	11S	4268070	607492	8N	55E	NE15	NV	NYE
Chimney Hot Sp.	2525	11S	4257946	605314	7N	55E	C16	NV	NYE
Storm Sp.	2526	11S	4250631	599354	6N	54E	SE11	NV	NYE
Coyote Hole Sp.	2527	11S	4249509	598969	6N	54E	14	NV	NYE
Abel Sp.	2528	11S	4246934	598897	6N	54E	NW23	NV	NYE
Hardy Sp.	735	11S	4278189	667570	9N	61E	SW12	NV	NYE
Moorman Sp.	736	11S	4273406	662044	9N	61E	NE32	NV	WHITEPINE
Ruppes Boghole -A	737A	11S	4290636	669532	10N	62E	SE6	NV	WHITEPINE
Ruppes Boghole -B	737B	11S	4290653	669554	10N	62E	SE6	NV	WHITEPINE
Sammy Sp.	203	11S	4366486	644187	18N	59E	NW15	NV	WHITEPINE
Bennett Sp.	223	11S	4370896	681971	19N	63E	SE33	NV	WHITEPINE
Grass Sp.-A	694A	11S	4374750	679444	19N	63E	SW17	NV	WHITEPINE
Grass Sp.-B	694B	11S	4374765	679469	19N	63E	SW17	NV	WHITEPINE
Cold Sp.	2073	11S	4396410	688670	21N	63E	SE12	NV	WHITEPINE
Unnamed Sp., S. of Cherry Ck.	2072	11S	4400499	687641	22N	63E	NE36	NV	WHITEPINE
Unnamed Sp. ,North of Green Ranch	2042	11S	4434812	691360	25N	64E	NE17	NV	WHITEPINE
Unnamed Sp., S. of Green Ranch	2047	11S	4432100	690709	25N	64E	SW20	NV	WHITEPINE
Unnamed Sp., North of Cherry Creek Ranch	2056	11S	4432262	690744	25N	64E	SW20	NV	WHITEPINE
Unnamed Sp., North of Cherry Creek Ranch	2057	11S	4432279	690778	25N	64E	SW20	NV	WHITEPINE
Unnamed Sp., North of Cherry Creek Ranch	2058	11S	4432825	690856	25N	64E	SW20	NV	WHITEPINE
Dolly Varden Sp.	230	11S	4465925	718864	28N	67E	NW9	NV	ELKO
Flat Sp.-A	218A	11S	4438082	714794	25N	66E	SW2	NV	ELKO
Flat Sp.-B	218B	11S	4438185	714854	25N	66E	SW2	NV	WHITEPINE
Unnamed Sp., South East Soldier Meadow	1990	11T	4578599	318533	40N	25E	SW29	NV	HUMBOLDT

	ID #	ZONE	North	East	Twnshp	Range	SEC	State	County
Unnamed Sp. West of Cane Sp.	2376	11T	4545908	307393	36N	24E	SE7	NV	HUMBOLDT
Morley Place Sp.-B	645B	11T	4546465	318677	36N	25E	NW5	NV	HUMBOLDT
Buck Sp.	648	11T	4550617	314567	37N	24E	NE26	NV	HUMBOLDT
Unnamed Sp. Nr. Jackass Flat	649	11T	4551235	318636	37N	25E	NW20	NV	HUMBOLDT
Unnamed Sp, Nr. Wagner	650	11T	4556443	317680	37N	25E	NE6	NV	HUMBOLDT
McConnel Sp.	2431	11T	4563081	303923	38N	23 E	12	NV	WASHOE
Little Smokey Sp.-A	580A	11T	4561324	305493	38N	23 1/2 E	24NW	NV	HUMBOLDT
Little Smokey Sp.-B	580B	11T	4561377	305851	38N	23 1/2 E	24NW	NV	HUMBOLDT
Little Smokey-C	580C	11T	4561446	305478	38N	23 1/2 E	24NW	NV	HUMBOLDT
North of Little High Rock "C", Source	586C	11T	4570801	296585	39N	23 E	NW30	NV	WASHOE
Wildcat, Source	635	11T	4522096	262270	34N	19 E	NW30	NV	WASHOE
Unnamed Sp., North of Little High Rock Lake-B	586B	11T	4570987	296305	39N	23 E	NW30	NV	WASHOE
Unnamed Sp., North of Little High Rock Lake-A	586A	11T	4570417	296068	39N	23 E	NW30	NV	WASHOE
Unnamed Cold Sp., Soldier Meadow	2530	11T	4581087	316337	40N	24E	NE24	NV	WASHOE
Warm Sp. Nr. Gridley Lk.	535	11T	4623966	346923	44N	27E	SW 12	NV	Humboldt
West Sp., W. of Gridley Lk	2523	11T	4621430	340221	44N	27E	NW20	NV	Humboldt
Chokecherry Sp.	484	11T	4645866	358197	46N	28E	NW 1	NV	Humboldt
Unnamed Sp., 1.6 km NW of Dyke	540	11T	4603480	368098	43N	30E	NW 25	NV	Humboldt
Unnamed Sp., Bishop Canyon	541	11T	4604777	367052	43N	30E	SW 23	NV	Humboldt
Road Sp.	527	11T	4611609	389834	44N	33E	NW 31	NV	Humboldt
Unnamed sp. 4.8km W. of 9 mile Sp.	525	11T	4618729	390686	44N	33E	NE 7	NV	Humboldt
Thacker Pass, N. of Road.	522	11T	4617261	407378	44N	34E	SE 11	NV	Humboldt
Unnamed east of Thacker Pass	524	11T	4613724	410414	44N	35E	SW 20	NV	Humboldt
Cold Sp, Santa Rosa Range	507	11T	4623814	462498	45N	40E	SE 22	NV	Humboldt
Unnamed, S.E. of Cold Sp Butte	506	11T	4621780	462873	45N	40E	SE 27	NV	Humboldt
Maiden Sp (west)	2264	11T	4628468	482590	45N	47E	SE 3	NV	Humboldt
Unnamed, Santa Rosa Range, SW of Mullinex.	505	11T	4601826	453327	43N	39E	NW 35	NV	Humboldt
Unnamed, Tony Cr drainage	514	11T	4580139	440890	40N	38E	SW 4	NV	Humboldt

	ID #	ZONE	North	East	Twnshp	Range	SEC	State	County
Hot Cr, 2 Mi S of Willow Cr Res.	939	11T	4559166	541121	38N	48E	SE 11	NV	Elko
Unnamed sp, 1.5mi SW of Midas	941	11T	4563677	515843	39N	46E	SW 29	NV	Elko
Unnamed at Ivanhoe	1940	11T	4556220	534903	38N	48E	NW20	NV	Elko
Sulfur Sp.	415	11T	4523743	470502	35N	41E	NW 34	NV	Humboldt
Jack Sp.	184	11S	4410467	548931	23N	49E	SE 23	NV	Eureka
Unnamed Sp., N of Carrico Lk	171	11T	4448057	508835	27N	45E	NE 27	NV	Lander
Indian Ck. @ Sp. Source	156	11T	4464727	524053	28N	47E	NE6	NV	Lander
Unnamed Sp., Lower Ferris Crk	157	11T	4463361	519841	28N	46E	SW 2	NV	Lander
Unnamed Sp., Corral Canyon	165	11T	4474769	524344	30N	47E	SE 31	NV	Lander
Crittenden Sp.	762	11T	4602794	736157	42N	69E	NE 8	NV	Elko
Gamble Sp.	765	11T	4583592	734782	40N	69E	NW 8	NV	Elko
Parson Sp.	764	11T	4559906	747605	38N	70E	NE 28	NV	Elko
McCuistion Sp.	763	11T	4550072	743199	37N	70E	NE 30	NV	Elko
Prather Sp	766	11T	4578401	688917	40N	64E	SE 21	NV	Elko
Willow Sp , Jarbidge Range	757	11T	4617878	646135	44N	60E	SW 18	NV	Elko
Unnamed, Nr Pole Crk.	753	11T	4570735	632328	39N	58E	SE 14	NV	Elko
Hot Sp., Lone Mtn	750	11T	4556559	587330	38N	53E	SE 25	NV	Elko
Willy Billy Sp.	168	11T	4496255	562004	32N	51E	SE 32	NV	Eureka
Unnamed Sp., Two Hill Cyn.	167	11T	4495498	561524	32N	51E	SW 31	NV	Eureka
Warm Sp., W. of Carlin	191	11T	4504055	571454	32N	52E	SW 5	NV	Eureka
Unnamed Sp., Nr. Thomas Ck.	162	11T	4484116	564911	30N	51E	NE 4	NV	Eureka
Bateman Sp.	417	11T	4487574	512286	31N	45E	SW 24	NV	Lander
Unnaned Sp. Nr Willow Ck.	414	11T	4494605	486816	32N	43E	SE 32	NV	Pershing
Kent Sp.	398	11T	4499804	456248	32N	40E	NW 18	NV	Pershing
Manganese Sp.	399	11T	4502735	454415	32N	39E	SE 1	NV	Pershing
Unnamed Sp. N. of Sand Hill	2253	11T	4420936	251635	24N	19E	SW31	NV	Washoe
Unnamed Sp., Dry Valley	2256	11T	4426498	248260	24N	18E	SW10	NV	Washoe
Miller Sp.	2257	11T	4427895	249500	24N	19E	NW10	NV	Washoe

	ID #	Elev (M)	SPRNG TYPE	DISCH	SPGBRK LGTH	Wetted Width	Water Depth	Water Velocity	Mean Substrate	Temp. °C
Marsh Sp.	1457	710	Rheocrene	30	50	44.8	3.2	27.4	80	30.0
Point of Rocks Sp.	1436	707	Limnocrene	2000	5000	367	23	50	45	30.5
Unnamed Sp. Nr Lida	390	1920	Rheocrene	<1	0	2.6	0.006	0	0.01	14.5
Indian Sp. #2	774	1230	Helocrene	1.65	17	4.4	3.02	4	11.44	21.8
Specie Sp.	775	1353	Rheocrene	0.00	0	0.78	3.01	1.8	3.41	21.1
Kwichup Sp.	94	1197	Hypocrene, piped to tank	0.46	0	0	0	0	N/A	27.5
Grapevine Sp.	25	1357	Rheocrene	11.20	500	134	5.2	4.0	11.4	19.9
Horseshootem Sp.	26	1482	Rheocrene	2.00	75	244	0.48	1.8	3.4	18.5
Lost Cabin Sp.	18	1552	Rheocrene	0.20	40	49.4	0.6	0.4	0.18	12.9
Potosi Sp.	10	1740	Piped, Unknown source	19.20	120	103	3.6	0.8	0.36	13.7
Potosi BSA Sp.	92	1660	Rheocrene	25.00	400	38.4	3.2	5.2	2.0	15.9
Mud Sp. #1	58	1172	Limnocrene	0.01	20	47.4	6.6	0.0	30.1	18.3
Calico Sp.	51	1104	Rheocrene	0.01	7	206	30.8	0.0	5.4	24.0
Willow Sp.	30	1812	Rheocrene	1074.10	1000	136.6	9.2	25.0	51.6	10.9
Willow Sp.-A	30A	1829	Rheocrene	1499.40	1000	191	8.2	30.0	38.0	11.2
White Rock Sp.	3	1464	Rheocrene	1.80	9	59.2	0.62	0.2	0.54	20
Lost Sp.	4	1373	Rheocrene	98.00	1000	159	4.6	8.2	16.5	15.2
Bitter Sp.	79	506	Rheocrene	4.00	200	131	2.6	1.6	6.4	22.7
Blue Point Sp.	80	483	Rheocrene	~500	3000	46.2	22.6	24.4	7.4	30
Rogers Sp.	81	472	Rheocrene	~1000	3000	82	13.4	54.4	14.1	20.9
Upper Valley of Fire Sp.	85	448	Helocrene	~1	1	65.6	8.8	0	1.0	23.8
Crow Sp.	300	1590	Rheocrene	7.12	170	192	0.7	0.6	1.12	16.4
Ice Plant Sp.	313	1850	Limnocrene	0.00	0	10	2.0	0	--	14.5
Warm Sp., Monitor Range	836	1985	Rheocrene	9.60	75	414	8.0	1.0	0.26	30.2
Mud Sp.	834	1840	Helocrene	0.00	1	15	1.5	0.0	0.1	23.1
Side Hill Sp.	838	1859	Gushet	12.60	1000	424	2.0	4.8	6.8	19.9
Point of Rocks Sp.	839	1843	Rheocrene	18.20	500	52.2	1.4	0.8	0.9	28.4

	ID #	Elev (M)	SPRNG TYPE	DISCH	SPGBRK LGTH	Wetted Width	Water Depth	Water Velocity	Mean Substrate	Temp. °C
Warm Sp., Monitor Range	840	1900	Helocrene	<2	300	1188	3	0.6	0.18	23.7
Black Sp.	825	1809	Hypocrene/ Limnocrene	0.00	0	10	2	0	1	18.1
Iceburg Sp.	903	1821	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Rattlesnake Sp.	904	1833	Cave Seep	<1	2	100	2	0	0.1	13
Blue Jay Sp.	833	1640	Dry	Dry	Dry	Dry	Dry	Dry	Dry	11.8
North Sp.	2293	1469	Limnocrene	727.20	1000	170.8	16.2	8.8	0.44	35.2
Hay Corral Sp.	2294	1464	Limnocrene	2212.80	1000	216	21	21.6	0.62	34.2
Reynolds Sp.-B	2295 B	1462	Limnocrene	690.50	20	167	13.2	6.8	1.2	36.2
ReynoldsSp.-A	2295 A	1462	Limnocrene	384.00	25	110	22.2	5.6	1.2	36.2
Chimney Hot Sp.	2525	1472	Limnocrene	30.00	300	42.6	1.4	0.8	0.8	100
Storm Sp.	2526	1467	Helocrene	1.80	20	56	4.8	1.4	0.9	33.4
Coyote Hole Sp.	2527	1471	Helocrene	~1	7	180	10.8	0	.8	33.7
Abel Sp.	2528	1466	Carbonate Mound	4.00	26	40.2	4.8	2.6	200.6	42.4
Hardy Sp.	735	1635	Rheocrene	285.00	1000	119	7.0	21.2	4.2	13.9
Moorman Sp.	736	1617	Rheocrene	677.40	500	73.4	10.8	17.4	1.8	36.2
Ruppes Boghole -A	737A	1674	Helocrene	1.00	300	2740	9.8	0	0.1	18.3
Ruppes Boghole -B	737B	1674	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Sammy Sp.	203	2035	Hillslope	9.40	220	518	4.0	2.2	0.5	11.7
Bennett Sp.	223	1857	Helocrene	3.00	32	570	7.25	0	0.1	14.8
Grass Sp.-A	694A	1863	Helocrene	58.00	1000	54.4	7.8	5.4	1.2	20.6
Grass Sp.-B	694B	1862	Helocrene	2.80	5	27	1.2	2.2	0.5	19
Cold Sp.	2073	1818	Helocrene	183.60	1000	169	15.6	2.0	0.4	10.9
Unnamed Sp., S. of Cherry Ck.	2072	1816	Helocrene	5.00	65	638	5.8	0.8	0.1	19.2
Unnamed Sp. ,North of Green Ranch	2042	1800	Helocrene	~0.5	35	26.4	0.65	0	0.2	10.4
Unnamed Sp., S. of Green Ranch	2047	1790	Helocrene	8.00	100	371	17.4	0.2	0.18	14.16

	ID #	Elev (M)	SPRNG TYPE	DISCH	SPGBRK LGTH	Wetted Width	Water Depth	Water Velocity	Mean Substrate	Temp. °C
Unnamed Sp., North of Cherry Creek Ranch	2056	1793	Helocrene	2.50	29	31.6	1.0	0.1	0.1	11.9
Unnamed Sp., North of Cherry Creek Ranch	2057	1793	Helocrene	4.10	60	104	1.1	0.4	0.1	12.3
Unnamed Sp., North of Cherry Creek Ranch	2058	1794	Helocrene	1.00	40	106	1.0	0.8	0.34	11.2
Dolly Varden Sp.	230	1730	Helocrene	5.65	100	91.6	3.2	3.8	1.34	18
Flat Sp.-A	218A	2002	Helocrene	3.00	28	44.6	1.6	0.4	0.84	14.4
Flat Sp.-B	218B	1998	Unknown	30.00	200	166	4.0	1.4	0.9	15.2
Unnamed Sp., South East Soldier Meadow	1990	1320	Helocrene	150 Est.	500	156.4	25.6	0.8	0.1	26.8
Unnamed Sp. West of Cane Sp.	2376	1445	Rheocrene	83.28	1000	75.2	2.8	22.0	9.3	21.5
Morley Place Sp.-A	645A	1320	Rheocrene	4.68	36	47	2.5	0.6	0.3	19.4
Morley Place Sp.-B	645B	1346	Rheocrene	2.24	40	74	1.6	2.0	3.0	17.5
Buck Sp.	648	1808	Rheocrene	2.76	18	128	2.2	3.4	2.0	16.5
Unnamed Sp. Nr. Jackass Flat	649	1317	Rheocrene	13.80	135	39	1.6	4.2	0.2	17.4
Unnamed Sp, Nr. Wagner	650	1580	Rheocrene	3.96	280	2.4	46.6	34.4	8	18.2
McConnel Sp.	2431	1572	Rheocrene	13.98	400	80	6.4	1.2	76.4	18
Little Smokey Sp.-A	580A	1628	Helocrene	42.75	26	71	2.3	11.0	5.2	19.2
Little Smokey Sp.-B	580B	1615	Helocrene	11.70	165	836	0.4	3.0	9.6	13.8
Little Smokey Sp.-C	580C	1615	Helocrene	28.50	40	150	1.6	2.8	1.3	21.3
North of Little High Rock "C"	586C	1647	Rheocrene	6.88	90	124	0.9	5.0	9.8	15.3
Wildcat Sp.	635	1604	Rheocrene	0.50	2	152	7.2	0	44.4	18.1
Unnamed Sp., North of Little High Rock Lake-B	586B	1656	Rheocrene	25.40	1000	90	3.0	6.8	24.9	17.3
Unnamed Sp., North of Little High Rock Lake-A	586A	1623	Rheocrene	33.60	600	66	1.6	8.8	10.2	20.7
Unnamed Cold Sp., Soldier Meadow	2530	1337	Limnocrene	25.7	150	87	16.8	3.2	0.5	13.4

	ID #	Elev (M)	SPRNG TYPE	DISCH	SPGBRK LGTH	Wetted Width	Water Depth	Water Velocity	Mean Substrate	Temp. °C
Warm Sp. Nr. Gridley Lk.	535	1364	Helocrene	183.00	450	169	4.7	15	0.5	37.1
West Sp., W. of Gridley Lk	2523	1409.0	Rheocrene	200.00	1000	252	6.4	9.6	20	21.4
Chokecherry Sp.	484	1423	Rheocrene	<1	300	40	4	0	0.3	12.4
Unnamed Sp., 1.6 km NW of Dyke	540	1389	Rheocrene	13.50	500	35	1	4.8		16.2
Unnamed Sp., Bishop Canyon	541	1435	Rheocrene	4.14	300	97	4	5.4	0.1	21
Road Sp.	527	1530	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Unnamed Sp. 4.8km W. of 9 mile Sp.	525	1739	Rheocrene	4.50	600	48	0.4	10	15	14
Thacker Pass, N. of Road.	522	1405	Rheocrene	36.60	300	75	1.2	4.4	1	19.6
Unnamed east of Thacker Pass	524	1643	Unknown	1.90	0	200	48	0	---	18.3
Cold Sp, Santa Rosa Range	507	1920	Rheocrene	21.00	500	131	8.8	0.6	0.1	7.4
Unnamed, S.E. of Cold Sp. Butte	506	1921	Rheocrene	0.00	0	40	3	0	0.1	18.3
Maiden Sp. (west)	2264	1866	Rheocrene	26.00	400	125	4.5	7.2	30	11.6
Unnamed Sp., Santa Rosa Range, SW of Mullinex.	505	1512	Rheocrene	6.00	75	180	3.8	1	0.1	13.9
Unnamed, Tony Cr drainage	514	1770	Rheocrene	3.00	30	50	1	1.4	0.1	15.5
Hot Cr, 2 mi S of Willow Cr Res.	939	1688	Rheocrene	242.88	2000	767	4.4	3.6	32.8	16.6
Unnamed Sp., 1.5mi SW of Midas	941	1725	Rheocrene	10.93	300	163	1.8	3.2	14	16.9
Unnamed Sp. at Ivanhoe	1940	1764	Rheocrene	5.00	30	124	3.1	1.6	0.1	13.8
Sulfur Sp.	415	1360	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Jack Sp.	184	2139	Helocrene	0.60	110	28	2	0.6	0.1	11
Unnamed Sp., N of Carico Lk.	171	1638	Rheocrene	2.00	100	264	1.8	0	0.1	16.8
Indian Ck. at Sp. Source	156	1638	Rheocrene	3.50	3000	104	19.4	0.4	0.1	16
Unnamed Sp., Lower Ferris Ck.	157	1760	Helocrene	<1	45	89	3.1	0.4	0.1	18.8
	ID #	Elev	SPRNG	DISCH	SPGBRK	Wetted	Water	Water	Mean	Temp.

		(M)	TYPE		LGTH	Width	Depth	Velocity	Substrate	°C
Unnamed Sp., Corral Canyon	165	1879	Rheocrene	69.40	1250	121	5.2	9.8	1	13.1
Crittenden Sp.	762	1616	Rheocrene	240.00	1000	226	3.8	25.2	31.6	17.6
Gamble Sp.	765	1520	Rheocrene	1071.00	1000	334	11.4	19.6	28.8	21.4
Parson Sp.	764	1820	Rheocrene	2.00	80	48	2.6	1	0.1	15.6
McCuistion Sp.	763	1660	Rheocrene	260.00	2000	108	7.8	7.2	20	16.4
Prather Sp.	766	1811	Rheocrene	500.00	2000	20	8.6	19.8	7	19.6
Willow Sp., Jarbidge Range	757	2032	Rheocrene	7.90	150	94	6.6	0.6	0.1	17
Unnamed Sp., Nr Pole Ck.	753	1896	Linmocrene	16.35	400	66	5.4	6.6	1	18.5
Hot Sp., Lone Mtn.	750	1963	Rheocrene	600.00	3000	200	7.2	26	20	20.7
Willy Billy Sp.	168	1695	Rheocrene	64.20	1000	68	2.5	2.2	1	14.1
Unnamed Sp., Two Hill Cyn.	167	1672	Unknown	<1	0	320	70	0	--	17
Warm Sp., W. of Carlin	191	1524	Rheocrene	1200.00	1000	323	5.2	38.2	70	21.8
Unnamed Sp., Nr. Thomas Ck.	162	1720	Rheocrene	<1	20	99	1.4	0	0.1	12.5
Bateman Sp.	417	1390	Rheocrene	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Unnamed Sp. Nr Willow Ck.	414	1961	Rheocrene	36.00	5000	76	2.6	8.8	79.4	12.4
Kent Sp.	398	1531	Rheocrene	50	1000	310	3.8	0.8	0.1	27.8
Manganese Sp.	399	1590	Mud Puddle	<1	23	300	3	0	0.8	27.8
Unnamed Sp. N. of Sand Hill	2253	1460	Helocrene	60	500	908	11.2	1.4	0.05	14.6
Unnamed Sp., Dry Valley	2256	1380	Rheocrene	<1	25	21.6	1.6	0.2	0.1	17.7
Miller Sp.	2257	1407	Helocrene	85	5000	284	4.6	1.8	0.1	22

	ID #	EC	pH	EMERG %	VGBNK %	STUBB	%FINE	%SAND	%GRAV	%COB	%BLDR	%BDRK
Marsh Sp.	1457	1810	7.4	60	80	30	0.00	50	0	0	0	50
Point of Rocks Sp.	1436	1671	7.5	10	100	30	10	30	40	0	0	0
Unnamed Sp. Nr Lida	390	914	8.2	0	0	0	100	0	0	0	0	0
Indian Sp. #2	774	301	7.95	95	60	5	90	5	5	0	0	0
Specie Sp.	775	667	7.44	5	3	0	85	5	5	4	1	0
Kwichup Sp.	94	1800	7.61	0	0	0	Plastic Tub	Plastic Tub	Plastic Tub	Plastic Tub	Plastic Tub	Plastic Tub
Grapevine Sp.	25	578	7.3	80	25	1	45	45	5	3	2	0
Horshootem Sp.	26	368	7.34	10	5	1	48	38	8	6	0	0
Lost Cabin Sp.	18	760	7.8	40	80	10	90	10	0	0	0	0
Potosi Sp.	10	479	7.28	100	80	5	92	7	1	0	0	0
Potosi BSA Sp.	92	377	7.65	95	100	20	68	4	28	0	0	0
Mud Sp. #1	58	990	7.61	0	80	N/A	36	16	16	32	0	0
Calico Sp.	51	758	7.97	5	20	4	2.5	2.5	5	30	20	40
Willow Sp.	30	303	8.23	5	85	15	3	4	62	31	0	0
Willow Sp.-A	30A	306	7.59	35	95	N/A	2	8	68	22	0	0
White Rock Sp.	3	591	7.51	98	100	15	96	2	2	0	0	0
Lost Sp.	4	420	7.24	60	90	N/A	76	22	1	1	0	0
Bitter Sp.	79	3621	7.54	0	15	0	6	60	34	0	0	0
Blue Point Sp.	80	4351	7.14	0.6	100	30	50	42	8	0	0	0
Rogers Sp.	81	3863	7.5	5	100	30	0	9	91	0	0	0
Upper Valley of Fire Sp.	85	17360	7.41	0	10	30	0	100	0	0	0	0
Crow Sp.	300	616	8.03	90	100	10	98	1	1	0	0	0
Ice Plant Sp.	313	498	7.23	0	100	8	50	40	10	0	0	0
Warm Sp., Monitor Range	836	480	8.07	5	10	3	100	0	0	0	0	0
Mud Sp.	834	286.9	8.71	0	50	5	100	0	0	0	0	0
Side Hill Sp.	838	245.6	7.64	100	100	5	100	0	0	0	0	0
Point of Rocks Sp.	839	9460	9.45	40	40	1.5	20	80	0	0	0	0
Warm Sp., Monitor Range	840	650	8.3	90	35	1.5	100	0	0	0	0	0
Black Sp.	825	438	7.65	0	60	12	50	50	0	0	0	0
Iceburg Sp.	903	Dry	Dry	Dry	Dry	30	Dry	Dry	Dry	Dry	Dry	Dry

	ID #	EC	pH	EMERG %	VGBNK %	STUBB	%FINE	%SAND	%GRAV	%COB	%BLDR	%BDRK
Rattlesnake Sp.	904	128	7.82	0	0	3	30	30	10	0	0	30
Blue Jay Sp.	833	938	7.9	80	10	2		0	0	0	0	0
North Sp.	2293	827	7.12	30	85	20	72	28	0	0	0	0
Hay Corral Sp.	2294	809	7.01	90	100	30	60	40	0	0	0	0
Reynolds Sp.-B	2295 B	835	7.05	10	100	20	0	100	0	0	0	0
Reynolds Sp.-A	2295 A	835	7.05	10	100	20	0	100	0	0	0	0
Chimney Hot Sp.	2525	693	7.7	0	20	20	50	50	0	0	0	0
Storm Sp.	2526	1396	6.51	35	100	30	40	40	0	0	0	20
Coyote Hole Sp.	2527	1319	7.05	75	90	20	100	0	0	0	0	0
Abel Sp.	2528	1123	6.48	5	70	3	0	80	0	0	0	20
Hardy Sp.	735	451.9	7.2	25	90	4	0	60	40	0	0	0
Moorman Sp.	736	558	7.15	30	100	20	0	80	20	0	0	0
Ruppes Boghole -A	737A	526	7.77	90	95	4	100	0	0	0	0	0
Ruppes Boghole -B	737B	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Sammy Sp.	203	327	7.94	100	35	3	60	40	0	0	0	0
Bennett Sp.	223	297	7.56	85	85	5	100	0	0	0	0	0
Grass Sp.-A	694A	422.6	7.64	35	90	10	40	60	0	0	0	0
Grass Sp.-B	694B	362	7.47	35	90	10	100	0	0	0	0	0
Cold Sp.	2073	375	7.38	90	35	3	96	4	0	0	0	0
Unnamed Sp., S. of Cherry Ck.	2072	367	7.94	90	90	3	100	0	0	0	0	0
Unnamed Sp., North of Green Ranch	2042	283	8.04	60	75	20	100	0	0	0	0	0
Unnamed Sp., S. of Green Ranch	2047	403.4	7.66	80	90	3	100	0	0	0	0	0
Unnamed Sp., North of Cherry Creek Ranch	2056	304	7.76	70	90	3	100	0	0	0	0	0
Unnamed Sp., North of Cherry Creek Ranch	2057	2906	8.26	80	95	3	100	0	0	0	0	0
Unnamed Sp., North of Cherry Creek Ranch	2058	341.5	7.8	80	50	3	100	0	0	0	0	0
Dolly Varden Sp.	230	429.2	7.82	15	25	2	74	16	0	0	0	0

	ID #	EC	pH	EMERG %	VGBNK %	STUBB	%FINE	%SAND	%GRAV	%COB	%BLDR	%BDRK
Flat Sp.-A	218A	217.8	8.16	95	100	25	80	20	0	0	0	0
Flat Sp.-B	218B	340	7.97	100	65	5	60	40	0	0	0	0
Unnamed Sp., South East Soldier Meadow	1990	275	7.18	95	100	10	100	0	0	0	0	0
Unnamed Sp. West of Cane Sp.	2376	324	7.7	30	40	5	60	20	20	0	0	0
Morley Place Sp.-A	645A	320	8.23	85	90	2	100	0	0	0	0	0
Morley Place Sp.-B	645B	309	7.78	75	70	5	40	40	20	0	0	0
Buck Sp.	648	252	7.75	30	50	2	65	29	3	3	0	0
Unnamed Sp. Nr. Jackass Flat	649	319	7.62	55	80	4	100	0	0	0	0	0
Unnamed Sp., Nr. Wagner	650	206	7.6	75	100	200	0	83	11	6	0	0
McConnel Sp.	2431	165	8.08	20	90	20	12	16	9	63	0	0
Little Smokey Sp.-A	580A	241	7.46	28	80	5	29	43	28	0	0	0
Little Smokey Sp.-B	580B	158	7.79	80	100	6	5	9	37	49	0	0
Little Smokey-C	580C	251	7.56	66	95	4	17	73	0	0	0	0
North of Little High Rock C	586C	91.6	7.19	57	95	2	8	15	57	20	0	0
Wildcat Sp.	635	305.9	7.18	100	90	5	32	0	6	62	0	0
Unnamed Sp., North of Little High Rock Lake-B	586B	99	7.58	0	85	5	0	6	35	40	0	19
Unnamed Sp., North of Little High Rock Lake-A	586A	105	7.4	8	95	15	1	41	54	1	0	0
Unnamed Cold Sp., Soldier Meadow	2530	380	7.5	20	100	15	30	70	0	0	0	0
Warm Sp. Nr. Gridley Lk.	535	211	8.15	95	95	8	62	27	11	0	0	0
West Sp., W. of Gridley Lk	2523	134	7.36	67	100	25	13	46	41	0	0	0
Chokecherry Sp.	484	801	7.37	0	20	2	50	50	0	0	0	0
Unnamed Sp., 1.6 km NW of Dyke	540	447	7.87	6	15	7	60	0	40	0	0	0
Unnamed Sp., Bishop Canyon	541	357	7.75	40	90	7	60	20	20	0	0	0
Road Sp.	527	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	ID #	EC	pH	EMERG	VGBNK	STUBB	%FINE	%SAND	%GRAV	%COB	%BLDR	%BDRK

	ID #	EC	pH	% EMERG	% VGBNK	STUBB	%FINE	%SAND	%GRAV	%COB	%BLDR	%BDRK
Unnamed sp. 4.8km W. of 9 mile Sp.	525	293	7.65	65	95	30	14	16	70	0	0	0
Thacker Pass, N. of Road.	522	275	7.84	70	70	20	20	40	20	20	0	0
Unnamed east of Thacker Pass	524	462	8.33	0	0	0	0	0	0	0	0	0
Cold Sp., Santa Rosa Range	507	89.2	8.76	95	100	40	82	14	4	0	0	0
Unnamed, S.E. of Cold Sp. Butte	506	372	7.08	5	70	20	70	20	0	10	0	0
Maiden Sp. (west)	2264	169	7.54	15	95	12	20	25	25	30	0	0
Unnamed, Santa Rosa Range, SW of Mullinex.	505	99	7.48	99	100	30	86	0	0	10	4	0
Unnamed Sp., Tony Ck. drainage	514	241	6.82	33	50	10	90	10	0	0	0	0
Hot Ck., 2 Mi S of Willow Ck. Res.	939	163.4	7.78	99	100	30	8	22	46	24	0	0
Unnamed Sp, 1.5mi SW of Midas	941	128.4	7.3	80	100	3	9	32	46	13	0	0
Unnamed Sp. at Ivanhoe	1940	161	7.53	75	30	10	71	10		8	11	0
Sulfur Sp.	415	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Jack Sp.	184	457	7.12	40	100	30	78	22	0	0	0	0
Unnamed Sp., N of Carico Lk.	171	574	7.31	98	100	30	98	2	0	0	0	0
Indian Ck. at Sp. Source	156	668	6.98	30	100	0	48	34	18	0	0	0
Unnamed Sp., Lower Ferris Ck.	157	843	7.12	90	100	0	88	12	0	0	0	0
Unnamed Sp., Corral Canyon	165	560	7.52	60	50	2	21	45	34	0	0	0
Crittenden Sp.	762	391	7.62	90	80	8	0	6	88	6	0	0
Gamble Sp.	765	395	7.48	95	95	30	4	35	57	4	0	0
Parson Sp.	764	166	7.44	0	70	1	76	4	20	0	0	0
McCuistion Sp.	763	173	7.07	85	90	30	0	16	40	44	0	0
Prather Sp.	766	371	7.45	18	50	3	0	40	60	0	0	0
Willow Sp., Jarbidge Range	757	95	6.75	60	100	30	100	0	0	0	0	0

				%	%							
Unnamed Sp., Nr Pole Ck.	753	200	7.41	95	100	40	36	40	16	8	0	0
Hot Sp., Lone Mtn.	750	376	7.6	75	85	0	2	16	60	22	0	0
Willy Billy Sp.	168	324	7.31	100	95	0	9	21	18	8	46	0
Unnamed Sp., Two Hill Cyn.	167	438	7.5	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
Warm Sp., W. of Carlin	191	408	8.12	5	95	30	0	2	16	66	16	0
Unnamed Sp., Nr. Thomas Ck.	162	552	8.45	0	9	2	84	16	0	0	0	0
Bateman Sp.	417	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Unnaned Sp. Nr Willow Ck.	414	358	7.92	65	25	2	8	13	41	38	0	0
Kent Sp.	398	479	8.91	65	30	10	100	0	0	0	0	0
Manganese Sp.	399	907	9.1	0	0	0	60	40	0	0	0	0
Unnamed Sp. N. of Sand Hill	2253	418	7.13	95	80	3	100	0	0	0	0	0
Unnamed Sp., Dry Valley	2256	390	7.36	98	95	25	100	0	0	0	0	0
Miller Sp.	2257	239	7.35	65	70	10	100	0	0	0	0	0

	ID #	FIRE	FLOOD	DRY	DIVERSION	UNGULAT	RECREA	DREDGE	AQUIFER ASS.
Marsh Sp.	1457	0	0	0	0	0	0	0	R
Point of Rocks Sp.	1436	0	0	0	0	0	0	2	R
Unnamed Sp. Nr Lida	390	0	0	0	0	3	0	0	B
Indian Sp. #2	2529	0	0	0	0	2	0	0	B
Specie Sp.	775	0	0	0	0	2	0	0	B
Kwichup Sp.	94	0	0	0	0	3	0	0	B
Grapevine Sp.	25	0	0	0	0	3	0	0	B
Horshootem Sp.	26	0	0	0	0	3	0	0	B
Lost Cabin Sp.	18	0	0	3	0	3	0	0	B
Potosi Sp.	10	0	0	1	3	3	1	0	M
Potosi BSA Sp.	92	0	0	0	0	0	2	0	M
Mud Sp. #1	58	0	0	3	0	3	0	0	M
Calico Sp.	51	0	3	0	0	2	1	0	B
Willow Sp.	30	0	0	0	0	0	1	0	M
Willow Sp.-A	30A	0	0	0	0	0	1	0	M
White Rock Sp.	3	0	0	0	3	0	2	0	M
Lost Sp.	4	0	0	0	0	0	1	0	M
Bitter Sp.	79	0	3	0	0	3	3	0	B
Blue Point Sp.	80	0	0	0	0	1	1	0	R
Rogers Sp.	81	0	0	0	3	0	3	0	R
Upper Valley of Fire Sp.	85	0	1	0	0	2	1	0	B
Crow Sp.	300	0	0	0	0	2	1	0	B
Ice Plant Sp.	313	0	0	1	1	3	1	0	B
Warm Sp., Monitor Range	836	0	0	0	1	3	0	1	G
Mud Sp.	834	0	0	3	0	3	1	0	B
Side Hill Sp.	838	0	0	0	0	2	1	0	B
Point of Rocks Sp.	839	0	0	0	0	3	1	1	B
Warm Sp.	840	0	0	0	0	3	0	0	G

	ID #	FIRE	FLOOD	DRY	DIVERSION	Disturbance UNGULAT	RECREA	DREDGE	AQUIFER ASS.
Black Sp.	825	0	0	0	1	3	0	0	B
Iceburg Sp.	903	0	0	3	1	0	0	0	M
Rattlesnake Sp.	904	0	0	0	1	3	0	0	M
Blue Jay Sp.	833	0	0	3	0	1	0	1	V
North Sp.	2293	0	0	0	0	1	1	0	G
Hay Corral Sp.	2294	0	0	0	1	1	1	1	G
Reynolds Sp.-B	2295B	0	0	0	0	1	1	0	G
Reynolds Sp.-A	2295A	0	0	0	0	1	1	0	G
Chimney Hot Sp.	2525	0	0	0	3	1	3	3	G
Storm Sp.	2526	0	0	0	2	2	0	0	G
Coyote Hole Sp.	2527	0	0	0	2	2	0	0	G
Abel Sp.	2528	0	0	0	0	3	1	0	G
Hardy Sp.	735	0	0	0	1	2	0	1	B
Moorman Sp.	736	0	0	0	2	2	0	1	G
Ruppes Boghole -A	737A	0	0	1	0	1	0	0	V
Ruppes Boghole -B	737B	0	0	3	0	3	0	0	V
Sammy Sp.	203	0	0	0	2	3	0	1	B
Bennett Sp.	223	0	0	0	0	3	0	0	V
Grass Sp.-A	694A	0	0	0	0	2	0	0	V
Grass Sp.-B	694B	0	0	0	0	2	0	0	V
Cold Sp.	2073	0	0	0	2	3	0	1	V
Unnamed Sp., S. of Cherry Ck.	2072	0	0	0	0	2	0	0	V
Unnamed Sp., North of Green Ranch	2042	0	0	0	0	2	0	0	V
Unnamed Sp., S. of Green Ranch	2047	0	0	0	0	2	0	1	V
Unnamed Sp., North of Cherry Creek Ranch	2056	0	0	0	0	2	0	0	V
Unnamed Sp., North of Cherry Creek Ranch	2057	0	0	0	0	3	0	0	V
Unnamed Sp., North of Cherry Creek Ranch	2058	0	0	0	0	3	0	0	V

	ID #	FIRE	FLOOD	DRY	DIVERSION	Disturbance UNGULAT	RECREA	DREDGE	AQUIFER ASS.
Dolly Varden Sp.	230	0	0	0	3	3	0	1	V
Flat Sp.-A	218A	0	0	0	1	0	0	1	B
Flat Sp.-B	218B	0	0	0	3	1	0	0	B
Unnamed Sp., South East Soldier Meadow	1990	0	0	0	0	0	0	0	V
Unnamed Sp. West of Cane Sp.	2376	0	0	0	0	2	0	0	B
Morley Place Sp.-A	645A	0	0	0	0	2	0	0	B
Morley Place Sp.-B	645B	0	0	0	0	2	0	0	B
Buck Sp.	648	0	0	0	3	1	1	0	M
Unnamed Sp. Nr. Jackass Flat	649	0	0	0	0	2	0	0	B
Unnamed Sp. Nr. Wagner	650	0	0	0	0	2	0	0	V
McConnel Sp.	2431	0	1	0	0	2	0	0	B
Little Smokey Sp.-A	580A	0	0	0	0	2	0	1	B
Little Smokey Sp.-B	580B	0	0	0	0	2	0	0	B
Little Smokey-C	580C	0	0	0	0	2	0	1	M
Unnamed Sp., North of Little High Rock-C	586C	0	0	0	0	2	0	0	M
Wildcat Sp.	635	0	0	0	0	3	0	0	M
Unnamed Sp., North of Little High Rock Lake-B	586B	0	0	0	0	2	0	0	M
Unnamed Sp., North of Little High Rock Lake-A	586A	0	0	0	0	2	0	0	B
Unnamed Cold Sp., Soldier Meadow	2530	0	0	0	0	0	0	0	V
Warm Sp. Nr. Gridley Lk.	535	0	0	0	0	2	1	1	G
West Sp., W. of Gridley Lk.	2523	0	0	0	0	2	0	0	V
Chokecherry Sp.	484	0	2	0	0	3	0	0	B
Unnamed Sp., 1.6 km NW of Dyke	540	0	0	0	3	3	2	3	M
Unnamed Sp., Bishop Canyon	541	0	0	0	0	3	0	0	M
Road Sp.	527	0	0	3	3	3	2	0	B
						Disturbance			

	ID #	FIRE	FLOOD	DRY	DIVERSION	UNGULAT	RECREA	DREDGE	AQUIFER ASS.
Unnamed sp. 4.8km W. of 9 mile Sp.	525	1	0	0	0	3	1	0	M
Thacker Pass, N. of Road.	522	0	0	0	0	2	0	1	B
Unnamed east of Thacker Pass	524	0	0	0	3	3	0	0	M
Cold Sp., Santa Rosa Range	507	0	0	0	0	2	1	0	M
Unnamed, S.E. of Cold Sp. Butte	506	0	0	3	0	3	0	0	M
Maiden Sp. (west)	2264	0	0	0	3	3	3	0	B
Unnamed, Santa Rosa Range, SW of Mullinex.	505	0	0	0	0	2	0	0	M
Unnamed, Tony Ck. drainage	514	0	0	0	0	3	0	0	M
Hot Ck., 2 mi S of Willow Ck Res.	939	0	0	0	0	2	0	0	G
Unnamed Sp, 1.5mi SW of Midas	941	0	0	0	2	2	0	0	B
Unnamed Sp. at Ivanhoe	1940	0	0	0	0	3	0	0	M
Sulfur Sp.	415	0	0	3	0	3	3	3	V
Jack Sp.	184	0	0	0	0	1	0	0	M
Unnamed Sp., N of Carico Lk	171	0	0	0	0	1	0	0	V
Indian Ck. at Sp. Source	156	0	1	0	0	3	0	0	M
Unnamed Sp., Lower Ferris Ck.	157	0	0	0	0	3	0	0	M
Unnamed Sp., Corral Canyon	165	0	1	0	0	3	2	0	M
Crittenden Sp.	762	0	0	0	2	2	1	0	M
Gamble Sp.	765	0	0	0	0	1	0	0	B
Parson Sp.	764	0	0	0	3	3	1	0	M
McCuistion Sp.	763	0	0	0	0	1	0	0	M
Prather Sp	766	0	0	0	0	3	0	0	B
Willow Sp., Jarbidge Range	757	0	0	0	0	2	0	0	M
Unnamed, Nr Pole Ck.	753	0	0	0	0	0	0	0	B
Hot Sp., Lone Mtn.	750	0	0	0	2	2	0	0	G
Willy Billy Sp.	168	0	0	0	0	2	0	0	M

Disturbance

	ID #	FIRE	FLOOD	DRY	DIVERSION	UNGULAT	RECREA	DREDGE	AQUIFER ASS.
Unnamed Sp., Two Hill Cyn.	167	1	0	3	3	2	0	0	M
Warm Sp., W. of Carlin	191	0	0	0	2	2	0	0	G
Unnamed Sp., Nr. Thomas Ck.	162	0	0	0	0	3	0	0	B
Bateman Sp.	417	0	0	3	0	3	0	0	V
Unnamed Sp. Nr Willow Ck.	414	0	0	0	0	3	2	0	M
Kent Sp.	398	0	2	0	0	3	0	0	V
Manganese Sp.	399	0	0	0	0	3	0	0	B
Unnamed Sp. N. of Sand Hill	2253	0	0	0	0	3	4	0	V
Unnamed Sp., Dry Valley	2256	0	0	3	0	2	0	0	B
Miller Sp.	2257	0	0	0	0	2	0	0	B

APPENDIX C: AQUIFER ASSOCIATIONS (FOLLOWING SADA AND THOMAS IN REVIEW) AND DESCRIPTION OF QUALITATIVE DISTURBANCE CATEGORIES (TAKEN FROM SADA AND POHLMANN 2006)

AQUIFER ASSOCIATION

Sada and Thomas (in review) found that the structure and functional characteristics of BMI communities in reference western Great Basin springs were associated with geochemistry, which is a function of aquifer characteristics and landscape setting. Distinct communities occupied springs located on mountain blocks, bajadas, valley floor alluvium, adjacent to playas, and springs fed by regional and geothermal aquifers. Each spring surveyed in 2012 and 2013 was classified as being fed by a mountain, regional, or geothermal aquifer, or discharging from bajada or valley floor alluvium.

DISTURBANCE EVALUATION

- **Site Condition:** This evaluation qualitatively identifies 1) disturbance factors stressing a spring and 2) the amount of stress of each factor on the spring environment. Harsh chemical conditions are not noted in this evaluation, but can be easily determined from water quality and EC measurements (e.g., harsh water chemistry occurs at temperatures > 30^oC, and EC > ~500 µmhos, etc.). To determine factors causing stress, look 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. Disturbance may be attributed to multiple factors at a single spring, such as trampling by intensive livestock and diversion into a trough; recreation use along a spring brook that tramples vegetation and the spring brook is channelized away from areas used for picnicking.

- Each spring is categorized as undisturbed, slightly, moderately, or highly disturbed. For CCA analysis, these categories are classified as: 1 = undisturbed, 2 = slightly disturbed, 3 = moderately disturbed, and 4 = highly disturbed. Springs with these levels of disturbance appear as:

- **<u>Undisturbed</u>** springs have been unaffected by recent or historical factors or activities. All 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 naturalizing from past disturbances.
- **<u>Slightly Disturbed</u>** 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 occur infrequently; riparian vegetation is vigorous.
- **<u>Moderately Disturbed</u>** springs exhibit evidence of recent, comparatively high disturbance. Use by native and non-native ungulates, and recreation has reduced vegetation height and coverage from natural conditions. Vegetation covers, hoof prints, footprints, and scat are common. Where there has been diversion, a spring box may be present but at least 50% of natural discharge remains within the natural spring brook. Neither the spring nor spring brook has been impounded. Where flooding or fire is apparent, > 50% of the spring brook banks are covered by vegetation; flood and fire are infrequent and the spring is naturalizing.
- **<u>Highly Disturbed</u>** springs have little similarity to undisturbed springs. Less than 50% of their banks are covered by vegetation, their spring brooks 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. Hoof prints and scat are abundant where ungulate use is heavy, and campsites are large, trashy, and vehicle use evident. These activities have decreased vegetative cover of spring brook banks to < 50%. Springs affected by drought (springs that are dry when sampled or experience seasonal or annual drying) should also be categorized as highly disturbed. These springs can be identified by the presence of upland riparian species 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 spring brooks are usually incised.

APPENDIX D: WATER CHEMISTRY OF SPRINGS SAMPLED IN SOUTHERN NEVADA DURING 2012

Spring Name	Spring ID No.	Sample Date	pH	EC uS/cm	SiO2 mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	NO3-N mgN/l	Na mg/l
CR12-01 Unnamed	391	5/22/2012	7.91	850	2.3	208	29.4	252	0.004	36.1
CR12-2 Indian#2	774	5/22/2012	7.43	291	3.1	122	14.7	20.3	1.37	57.2
CR12-04 Specie	775	5/22/2012	7.53	540	6.0	188	12.6	113	0.010	18.6
CR12-05 Kwichup	94	5/22/2012	7.79	1710	8.5	360	20.0	714	0.009	95.1
CR12-06 Grapevine 1	25	5/23/2012	7.49	548	5.3	162	15.4	123	0.281	24.7
CR12-07 Horshootem	26	5/23/2012	7.34	317	8.1	135	13.5	26.8	1.14	16.2
CR12-09 Lost Cabin	18	5/24/2012	7.35	760	11.2	244	20.7	170	0.261	29.6
CR12-10 Potosi	10	5/24/2012	7.32	457	5.5	270	8.0	20.4	0.560	6.55
CR12-11 Potosi BSA	92	5/24/2012	7.24	467	5.4	286	5.4	8.7	0.960	4.98
CR12-12 Mud Spg#1	58	5/24/2012	7.67	1130	13.6	227	23.2	420	0.023	39.6
CR12-13 Calico	51	5/24/2012	7.77	650	9.3	400	8.8	26.1	0.003	11.7
CR12-14 Willow Crk.	30A	5/24/2012	7.4	251	5.3	146	1.7	9.9	0.216	2.10
CR12-15 Willow Crk. Source	30	5/25/2012	7.18	368	5.4	189	1.8	10.6	0.249	2.22
CR12-16 White Rock	3	5/25/2012	7.37	616	9.5	147	19.4	177	0.017	7.53
CR12-17 Lost	4	5/25/2012	7.47	396	7.3	182	3.5	55.8	0.212	3.36
CR12-18 Bitter	79	5/26/2012	7.53	3690	14.6	118	160	2110	0.071	272
CR12-19 Blue Point	80	5/26/2012	7.32	3660	10.0	155	387	1554	0.217	331
CR12-20 Rogers	81	5/26/2012	7.53	3180	10.3	137	298	1400	0.264	255
CR12-21 Upper Valley of Fire	85	5/26/2012	7.86	17700	26.0	593	3220	7040	0.002	3150

Spring Name	Spring ID No.	Sample Date	K mg/l	Ca mg/l	Mg mg/l	NO2-N mg/l	NH3-N mg/l	OPO4-P mg/l	TP mg/l
CR12-01 Unnamed	391	5/22/2012	1.50	90.3	42.8	<.002	0.013	0.003	0.005
CR12-2 Indian#2	774	5/22/2012	1.60	6.71	0.98	0.021	0.054	0.051	0.051
CR12-04 Specie	775	5/22/2012	5.55	64.6	20.2	<.002	2.57	0.005	0.397
CR12-05 Kwichup	94	5/22/2012	2.42	102	139	<.002	0.008	0.002	0.010
CR12-06 Grapevine 1	25	5/23/2012	1.64	25.5	39.7	<.002	0.010	0.003	0.010
CR12-07 Horshootem	26	5/23/2012	1.07	21.3	18.0	<.002	0.004	0.006	0.018
CR12-09 Lost Cabin	18	5/24/2012	6.34	62.1	47.2	0.018	0.261	0.041	0.837
CR12-10 Potosi	10	5/24/2012	0.79	28.1	41.9	<.002	0.005	0.003	0.014
CR12-11 Potosi BSA	92	5/24/2012	1.04	24.6	47.4	0.002	0.009	0.003	0.006
CR12-12 Mud Spg#1	58	5/24/2012	3.25	147	50.1	<.002	0.033	0.007	0.018
CR12-13 Calico	51	5/24/2012	3.65	27.9	70.0	<.002	0.005	0.004	0.007
CR12-14 Willow Crk.	30A	5/24/2012	0.58	25.3	16.8	<.002	0.005	0.004	0.015
CR12-15 Willow Crk. Source	30	5/25/2012	0.59	41.5	16.6	<.002	0.003	0.006	0.014
CR12-16 White Rock	3	5/25/2012	1.82	76.8	28.7	<.002	0.087	0.021	0.046
CR12-17 Lost	4	5/25/2012	2.66	29.2	31.8	<.002	0.004	0.005	0.016
CR12-18 Bitter	79	5/26/2012	21.8	428	193	<.002	0.005	0.017	0.038
CR12-19 Blue Point	80	5/26/2012	24.2	319	165	<.002	<.002	0.003	0.004
CR12-20 Rogers	81	5/26/2012	19.0	331	127	<.002	0.003	0.003	0.003
CR12-21 Upper Valley of Fire	85	5/26/2012	251	338	993	<.002	0.006	0.010	0.010

APPENDIX E: BIOASSESSMENT METRICS

Arrows show the metric trend with increasingly harsh or degraded conditions.

Richness	The total number of taxa in a sample. ↓
Shannon H	A measure of taxonomic richness also considering evenness ↓
Evenness	The equalability of taxa abundance in the BMI community ↓
Mayfly Richness	The number of mayfly taxa (Oder Ephemeroptera) in the BMI community. ↓
Stonefly Richness	The number of stonefly taxa (Order Plecoptera) in the BMI community. ↓
Caddisfly Richness	The number of caddisfly taxa (Order Trichoptera) in the BMI community. ↓
Mite Richness	The number of mite taxa in a sample. ↑
EPT Richness	The number of mayflies, stoneflies, and caddisflies in the BMI community. ↓
Midge Richness	The number of Chironomid taxa in the BMI community. ↑
Percent Mayflies	Percent of the BMI community that are mayflies. ↓
Percent Stoneflies	Percent of the BMI community that are stoneflies. ↓
Percent Caddisflies	Percent of the BMI community that are caddisflies. ↓
Percent Gastropods	Percent of the BMI community that are gastropods (snails) ↓
Percent Bivalves	Percent of the BMI community that are bivalves (clams). ↑
Percent Ostracoda	Percent of the BMI community that are ostracods (water fleas). ↑
Percent Naididae	Percent of the BMI community that are naidid worms. ↑
Percent Tubificidae	Percent of the BMI community that are tubificid worms. ↑
HBI	Hilsenhoff Biotic Index calculated for a BMI community. Higher values (>6) indicate communities comprised of taxa that are more tolerant of harsh or polluted conditions, lower values (<4) indicate communities comprised of taxa that are more intolerant of harsh or polluted conditions (Hilsenhoff 1987). ↑
Percent Tolerant EPT	Percent of the EPT community with a Tolerance Index that is >7. ↑
Percent Intolerant EPT	Percent of the EPT community with a Tolerance Index that is <3. ↓
Percent Intolerant (community)	Percent of the BMI community with a Tolerance Index that is <3. ↓
Percent Intolerant (taxa)	Percent of the number of taxa in the BMI community with Tolerance Index <3. ↓
Percent Tolerant (community)	Percent of the BMI community with a Tolerance Index that is >7. ↑
Percent Tolerant (community)	Percent of the BMI community with Tolerance Index >7. ↑
Percent Collector-Gathers	The percent of the BMI community that feed by collecting and gathering. ↓

Percent Scrapers	The percent of the BMI community that feed by scraping from the substrate. ⇩
Percent Shredders	The percent of the BMI community that feed by shredding. ⇩
Percent Burrowers	The percent of the BMI community that burrow in the substrate. ⇧

APPENDIX F: PHOTOGTRAPHS OF REPRESENTIVE SPRINGS WITH DIFFERENT DISTURBANCE LEVELS

Figure F1. Undisturbed condition spring. Unnamed cold spring, Soldier Meadow, Humboldt County, NV (spring ID No. 2530, Field Note No. CR13-12, June 18, 2013).

Figure F2. Slight disturbance condition. Blue Point Spring, Lake National Recreation Area, Clark County, NV (spring ID No. 80, Field Note No. CR12-19, May 26, 2012).

Figure F3. Moderate disturbance condition. Specie Spring, Clark County, NV (spring ID No. 775, Field Note No. CR12-04, May 22, 2012).

Figure F4. 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, June 12, 2012).

Figure F5. 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, June 12, 2012).

Figure F6. High disturbance condition, caused by diversion and ungulates. Unnamed Spring, 2 km SE of Lida, Esmeralda County, NV (spring ID No. 390, Field Note No. CR12-01, May 22, 2012).

Figure F7. High disturbance condition, caused by diversion and recreation. White Rock Spring, Clark County, NV (spring ID No. 3, Field Note No. CR12-16, May 25, 2012).

APPENDIX G: TAXA OCCURING IN > 10% OF NEVADA SPRINGS SAMPLED IN 2012 AND 2013, AND USED IN MULTIVARIATE ANALYSIS

Higher Taxonomy	Genus	Higher Taxonomy	Genus
Ephemeroptera	Baetis	Diptera (cont')	Radotanypus
	Callibaetis		Larsia
	Fallceon		Nilotanypus
Plecoptera	Isoperla		Paramerina
Trichoptera	Helicopsyche		Pentaneura
	Hydroptila		Thienemannimyia grp.
	Ochrotrichia		Dixa
	Lepidostoma		Dixella
	Hesperophylax		Lemnaphila
	Wormaldia		Scatella
	Gumaga		Telmatoscopus/Pericoma
Coleoptera	Agabus		Ectemnia
	Laccobius		Simulium
	Uvarus		Caloparyphus
	Microcylloepus		Stratiomys
	Optioservus		Tabanus
	Zaitzevia		Limnophila
	Tropisternus	Odonata	Argia
	Ceratopogon	Mites	Arrenurus
Diptera	Bezzia/Palpomyia		Limnesia
	Apedilum		Oribatei
	Chironomus		Testudacarus
	Djalmabatista		Torrenticola
	Paratendipes		Hydrozetes
	Polypedilum	Ostracodes	Class Ostracoda
	Polypedilum cf. flavum	Crustacea	Hyalella
	Polypedilum cf. simulans-digitifer		Gammarus
	Polypedilum cf. scalaenum		Stygobromus
	Micropsectra/Tanytarsus	Gastropods	Fluminicola
	Paratanytarsus		Pyrgulopsis
	Brillia		Physa
	Chaetocladius		Fossaria
	Corynoneura	Bivalves	Pisidium
	Cricotopus (distinct)	Flatworms	Tricladida

Higher Taxonomy	Genus	Higher Taxonomy	Genus
	Cricotopus/Orthocladius Distinct	Phylum Nematoda	Phylum Nematoda
	Cricotopus (Isocladius grp.)	Annelid Worms	Lumbriculidae
	Eukiefferiella claripennis grp.		Enchytraeidae
	Limnophyes		Naididae
	Metriocnemus		Pristina
	Parachaetocladius		Pristinella
	Parametriocnemus		Nais
	Pseudorthocladius		Tubificidae
	Thienemanniella		Helobdella
	Tvetenia bavarica grp.		