



Aquatic Invertebrate Community Structure in Springs at Ozark National Scenic Riverways, Missouri, 2007–2016

Natural Resource Data Series NPS/HTLN/NRDS—2018/1161





ON THIS PAGE

Blue Spring, Ozark National Scenic Riverways, Missouri.

Photography by NPS/Heartland Inventory and Monitoring Network

ON THE COVER

Pulltite Spring, Ozark National Scenic Riverways, Missouri

Photography by NPS/Heartland Inventory and Monitoring Network

Aquatic Invertebrate Community Structure in Springs at Ozark National Scenic Riverways, Missouri, 2007–2016

Natural Resource Data Series NPS/HTLN/NRDS—2018/1161

David E. Bowles,¹ Hope R. Dodd,¹ Janice A. Hinsey,¹ Tyler Cribbs,¹ Jeffrey M. Williams²

¹National Park Service
The Heartland I&M Network
Wilson's Creek National Battlefield
6424 West Farm Road 182
Republic, Missouri 65738

²Department of Biology
Missouri State University
901 South National Avenue
Springfield, Missouri 65897

Editing and Design by

Tani Hubbard

National Park Service &
Northern Rockies Conservation Cooperative
12661 E. Broadway Blvd.
Tucson, AZ 85748

May 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from [Heartland I&M Network website](#), and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Bowles, D. E., H. R. Dodd, J. A. Hinsey, J. T. Cribbs, and J. M. Williams. Aquatic invertebrate community structure in springs at Ozark National Scenic Riverways, Missouri, 2007–2016. Natural Resource Data Series NPS/HTLN/NRDS—2018/1161. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures	iv
Tables	iv
Executive Summary	v
Acknowledgments	vi
Introduction	1
Methods	3
Reach Selection	3
Aquatic Invertebrates	6
Water Quality and Quantity	6
Habitat	7
Analysis	7
Results	9
Aquatic Invertebrates	9
Alley Spring	10
Big Spring	11
Blue Spring	12
Pulltite Spring	13
Round Spring	14
Welch Spring	15
Phillips Spring	16
Water Quality	17
Habitat	17
Discussion	23
Literature Cited	24
Appendix A: List of Collected Aquatic Invertebrates	26
Appendix B: Water Quality Data	31

Figures

	Page
Figure 1. Map showing the locations of large springs at Ozark National Scenic Riverways, Missouri.	5
Figure 2. Transect location and layout within a spring run.	6
Figure 3. Community diversity metrics for aquatic invertebrates collected at Alley Spring, Ozark National Scenic Riverways, Missouri, 2007-2016.	10
Figure 4. Community diversity metrics for aquatic invertebrates collected at Big Spring, Ozark National Scenic Riverways, Missouri, 2007-2016.	11
Figure 5. Community diversity metrics for aquatic invertebrates collected at Blue Spring, Ozark National Scenic Riverways, Missouri, 2007-2016.	12
Figure 6. Community diversity metrics for aquatic invertebrates collected at Pulltite Spring, Ozark National Scenic Riverways, Missouri, 2007-2016.	13
Figure 7. Community diversity metrics for aquatic invertebrates collected at Round Spring, Ozark National Scenic Riverways, Missouri, 2007-2016.	14
Figure 8. Community diversity metrics for aquatic invertebrates collected at Welch Spring, Ozark National Scenic Riverways, Missouri, 2007-2016.	15
Figure 9. Community diversity metrics for aquatic invertebrates collected at Phillips Spring, Ozark National Scenic Riverways, Missouri, 2011, 2013, and 2016.	16

Tables

	Page
Table 1. Ozark National Scenic Riverways springs chosen for long-term monitoring.	4
Table 2. Habitat cover value scale used for assessing coverage of in-stream and fish cover habitat variables.	7
Table 3. Acceptable ranges for water quality parameters in Missouri Ozarks coldwater streams.	17
Table 4. Habitat metrics for aquatic invertebrate samples collected at springs located at Ozark National Scenic Riverways.	18
Table 5. Discharge (m ³ /sec) for springs located at Ozark National Scenic Riverways, 2007-2016.	22

Executive Summary

The extensive karst topography in the area surrounding Ozark National Scenic Riverways contributed to the formation of more than 425 springs within the park. Springs at Ozark National Scenic Riverways receive portions of their baseflows from deeper karst components as well as surficial groundwater traveling through a karst landscape. Contaminates from land and surface water are known to enter surficial groundwater through rapid recharge, facilitated by the soluble bedrock system of fissures and sinkholes. Pollutants can be conveyed over great distances to springs through relatively unimpeded interbasin and subsurface transport. Land use practices, particularly land clearing and associated increases in sediment and nutrient loads, and other point and nonpoint discharges present the greatest long-term threat to springs in the Ozark Highlands. Little information exists on the physical and biological impacts of contaminated groundwater within springs or within surface water fed by springs.

The Heartland Inventory and Monitoring Network began a spring monitoring program in 2007 to provide a baseline for assessing impacts of anthropogenic and natural disturbances on the ecological integrity of springs at Ozark National Scenic Riverways. This report summarizes monitoring data on aquatic invertebrates, habitat, and water quality collected from Alley, Big, Blue, Pulltite, Round, and Welch springs at Ozark National Scenic Riverways from 2007 to 2016, and from Phillips Spring beginning in 2011. All water quality parameters monitored and the invertebrate communities indicate that conditions among the respective springs are good. The invertebrate fauna occurring in all of the springs was dominated by environmentally sensitive taxa. The dominance of intolerant taxa, mainly representatives of the caddisfly genus *Lepidostoma*, occurring in the springs indicates their respective water quality conditions and habitat are not disturbed. The findings presented here reflect the broad natural habitat diversity and physical and chemical stability in these springs. Collecting and analyzing additional monitoring data will help us to better understand invertebrate community dynamics in the springs.

Acknowledgments

We thank Victoria Grant, Catherine Ciak, Mike Gossett, John Dotten, Jennifer Haack, Ryan Green, Myranda Clark, Beth Bailey, Kevin Murray, Gina Botella, Melanie Weber, Zach Morris, Allison Keefe, Kristen Kohlhepp, Robin Graham, Chris Morris, Josh DeLay, Joe Chilton, Olivia Jackson, and Killian Kelly for assisting us with this project. Jessica Luraas was instrumental in sorting samples and identifying specimens. Lloyd Morrison, David VanderMeulen, Alex Egan, and Richard Damstra kindly reviewed an earlier draft of this report and provided constructive comments.

Introduction

Ozark National Scenic Riverways was established to conserve and interpret “unique scenic and other natural values and objects of historic interest, including preservation of portions of the Current River and the Jacks Fork River in Missouri as free-flowing streams, preservation of springs and caves, management of wildlife, and provisions for use and enjoyment of the outdoor recreation resources” (United States Code 1964).

The extensive karst topography in the area surrounding Ozark National Scenic Riverways is conducive to the formation of springs (Mugel et al. 2009). Within the karst terrain of Ozark National Scenic Riverways, there are more than 425 springs (Mugel et al. 2009). Although most of these springs are relatively small, seven are defined as 1st and 2nd magnitude, having discharges of at least 2.8 m³/second and 0.28 to 2.8 m³/second, respectively (Meinzer 1927). The largest (Big Spring) has a maximum-recorded discharge greater than 36 m³/sec and is ranked as one of the five largest springs in North America (Brune 1981). An additional 1st magnitude spring, Montauk,

serves as the source of the Current River, but it is located outside of park boundaries.

Springs at Ozark National Scenic Riverways receive portions of their baseflows from deeper karst components as well as surficial groundwater traveling through a karst landscape. Contaminates from land and surface water are known to enter surficial groundwater through rapid recharge, facilitated by the soluble bedrock system of fissures and sinkholes. Pollutants can be conveyed over great distances to springs through relatively unimpeded interbasin and subsurface transport. Karst springs have limited self-purification capacity because of low retention and adsorption within vast and often undescribed recharge areas. These springs are highly vulnerable to biological and chemical degradation and may represent the ultimate challenge in water quality protection (Gibert 1990; Imes and Fredrick 2002).

Despite the large amount of literature explaining groundwater contamination and its complexities, there is little information on the physical and



Downstream view from Phillips Spring, Ozark National Scenic Riverways, Missouri.

biological impacts of contaminated groundwater within springs or within surface water fed by springs (Williams 1991; Notenboom et al. 1994; van der Kamp 1995). Land use, particularly vegetation clearing practices with associated increases in sediment and nutrient loads and other point and nonpoint inputs to surface water, have been reported as the largest long-term threat to streams and springs in the Ozark Highlands (Duchrow 1977; Jacobson and Primm, 1997; Scott and Udouj 1999; Imes and Frederick 2002).

The extant conditions of the watersheds of the springs have changed appreciably relative to historic conditions. As noted by Benac and Flader (2004), the historic Ozark forest was largely deforested by the late 1920s resulting in heavy gravel and silt loads

entering waterways. The forest cover has now largely recovered, but it remains unclear what long-term and permanent damage was inflicted on the springs and their respective biotic communities (Bowles and Dodd 2015). Potential impacts to spring integrity include disrupted stream channel geomorphology, increased sediment deposition and bank erosion, increased light penetration and water temperature, increased periphyton biomass resulting from nutrient loading, and decreased leaf litter and woody debris. Recent studies of the possible effects of global climate change indicate that increases in annual average water temperature (Hogg and Williams 1996; Poff et al. 2002; Johnson 2007) and changes in discharge (Erman and Erman 1995) may impact spring communities as well.

Methods

Reach Selection

Methods used in this study follow Bowles et al. (2008). Beginning in 2007, aquatic invertebrates were collected annually (late July-early August) at six large springs ($>0.28 \text{ m}^3/\text{sec}$; Table 1) located at Ozark National Scenic Riverways, Missouri (Figure 1). In 2012, we switched to monitoring these parameters on a rotating basis every three years. These springs were studied because they are the largest in the park and of greatest concern to park management. Data on invertebrates, water quality, and in-stream habitat were collected at each spring annually from 2007-2011. Phillips Springs was added to the list of springs that are monitored beginning in 2011 (DeBacker et al. 2011).

At each spring, a sampling reach was established that satisfied specific requirements necessary to obtain representative and unbiased samples for all abiotic and biotic parameters being monitored. The portion of the spring run to be sampled was unique, and driven by site-specific characteristics for each

spring. We applied a weighting factor that accounted for variation among average widths (Table 1) to ensure a uniform sampling effort that represented each spring's total area. Reach length was based on a weighting factor that used average wetted width and the minimum reach length established by National Water-Quality Assessment Program (Moulton et al. 2002; Bowles et al. 2008). The designated sampling reach lengths allowed for inclusion of representative macrohabitats (riffle, run, and pool habitats) present. Runs were the most common habitats among all habitat types within the springs.

The sampling reach of each spring began as close to the spring source as practical, taking into consideration depth, flow, and crew safety near the spring source. The sampling reach was divided into 11 equally spaced transects beginning at the most upstream point and proceeding downstream (Figure 2). The only exception to this was Welch Spring, where only three transects were used because the entire spring run is only 36 m long before its confluence with the Current River.



Upstream view from Welch Spring, Ozark National Scenic Riverways, Missouri.

Table 1. Ozark National Scenic Riverways springs chosen for long-term monitoring.

Spring Name	Spring Magnitude and Type (Meinzer 1927)	County	Quad Map	GPS Coordinates	Rate of Flow (m ³ /sec) (Vineyard et al. 1974)	Length (meters)	Average Width (meters)	Weight Factor (WF)	Reach Length = 150 m x WF (m)	Transect Interval (m)
Alley	1 st , conduit	Shannon	Alley Spring	N37° 9.247' W91° 26.499'	1.51-29.68	800	19	19/15 ≈ 1.3	190	19
Big	1 st , conduit	Carter	Big Spring	N36° 57.137' W90° 59.646'	6.61-36.40 (est.)	600	46	46/15 ≈ 3.1	460	46
Blue	1 st , conduit	Shannon	Powder Mill	N37° 9.956' W91° 9.789'	1.74-6.61	250	16	16/15 ≈ 1.1	160	16
Round	2 nd , conduit	Shannon	Round Spring	N37° 16.953' W91° 24.458'	0.28-14.56	575	15	15/15 ≈ 1.0	150	15
Phillips	2 nd , conduit	Carter	Big Spring	N36° 50.156' W90° 56.713'	0.25-0.55	250	15	15/15 ≈ 1.0	150	15
Pulltite	2 nd , conduit	Shannon	Round Spring	N37° 20.103' W91° 29.408'	0.16-3.98	300	24	24/15 ≈ 1.6	240	24
Welch	1 st , conduit	Shannon	Cedar Grove	N37° 23.631' W91° 34.459'	1.96-9.27	36	15	15/15 ≈ 1.0	36	18

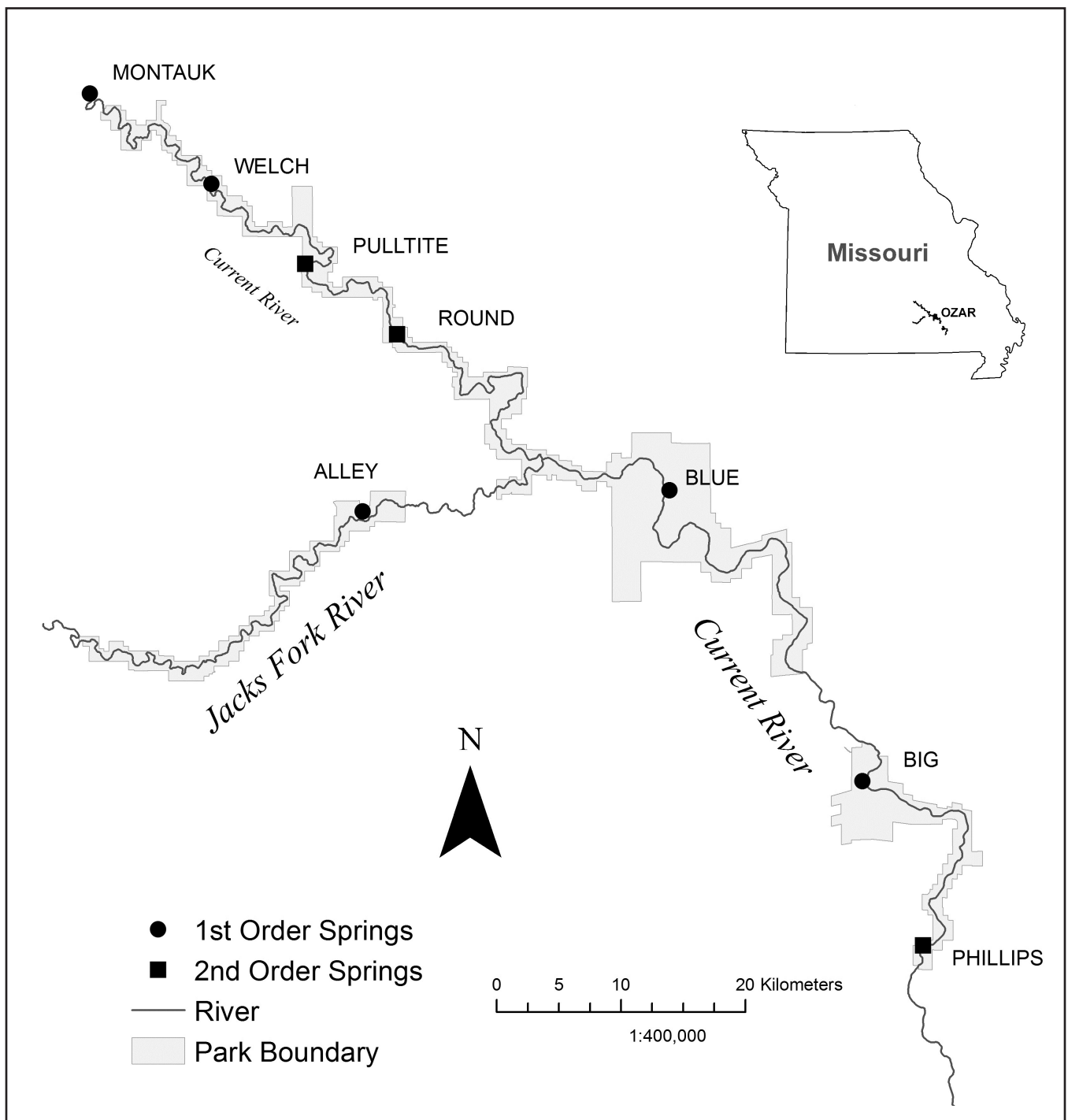


Figure 1. Map showing the locations of large springs at Ozark National Scenic Riverways, Missouri. Montauk Spring is outside of the park boundary and was not included in this study.

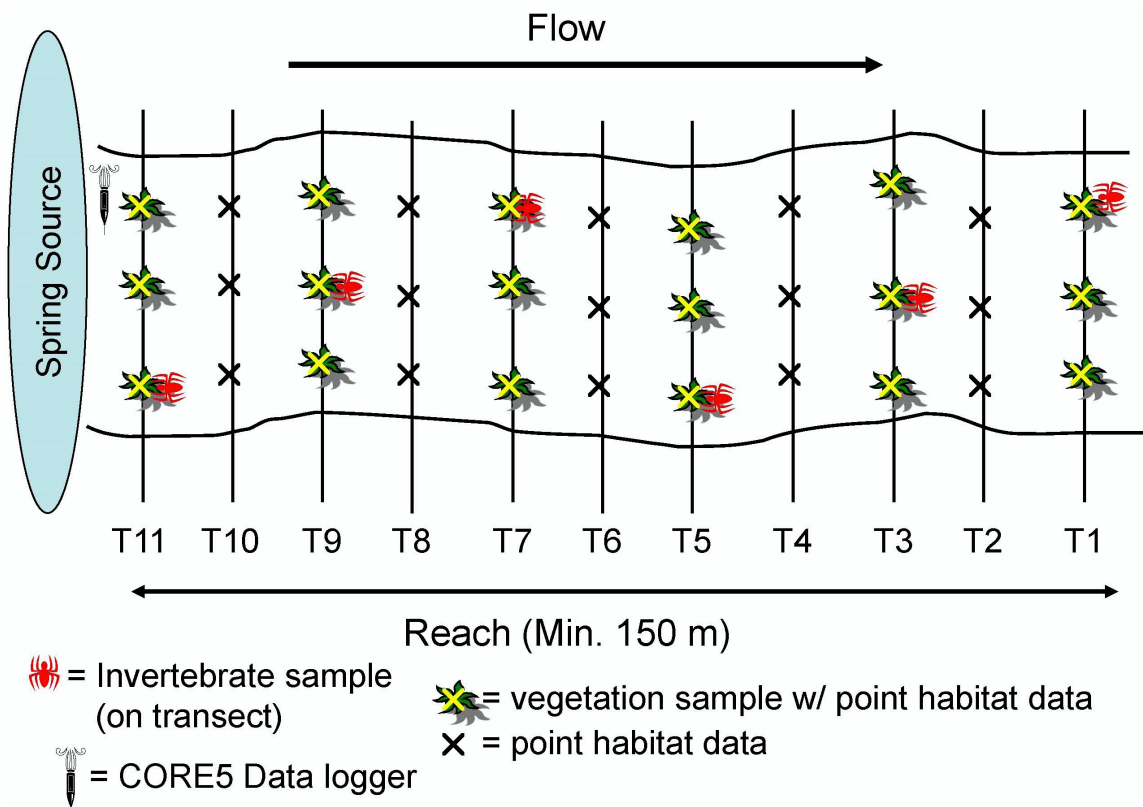


Figure 2. Transect location and layout within a spring run. The sampling reach at Welch Spring is only 36 meters and therefore has only three transects instead of 11.

Aquatic Invertebrates

For each spring, a single aquatic invertebrate benthic sample was collected at transects 10, 8, 6, 4, and 2, using a Slack-Surber sampler (500 μm mesh) with a 0.25-m² sample frame (Figure 2). Sample locations on transects alternated from left, middle, and right channel and starting location was rotated each year. This insured minimum long-term substrate disturbance to the spring runs. Samples were preserved in the field using isopropyl or ethyl alcohol. Samples were sorted in the laboratory following a subsampling routine described in Bowles et al. (2008). Taxa were identified to the lowest practical taxonomic level (usually genus) and counted. Metrics calculated for invertebrate data included taxa richness, Ephemeroptera, Plecoptera and Trichoptera (EPT) richness, percent intolerant taxa, percent dominant taxa (top three), Shannon's diversity index, Simpson's diversity index, and Hilsenhoff Biotic Index (HBI). Diversity data for invertebrates (Shannon's and Simpson's diversity indices) were expressed as effective number of species (Bowles et al. 2008).

Water Quality and Quantity

Water quality parameters (temperature, dissolved oxygen, specific conductance, pH, and turbidity) were recorded hourly for approximately 24 to 48 hours at the head of each spring reach using a pre- and post-calibrated data logger (YSI 6600 or YSI 6920). At Welch Spring, water quality parameters were measured as three static (point) readings at the upper, middle, and lower portion of the spring run. Stream discharge was measured using the methods of Carter and Davidian (1969). Discharge data for Big Spring were taken from United States Geological Survey registering (real-time) staff gage No. 07067500 at the approximate time of sampling.

The water quality and discharge data collected for this study are intended to describe the prevailing conditions that influence the structure of the biotic communities. These data represent only a small snapshot of the broader range of possible conditions over longer periods and should be cautiously interpreted. As such, they may help explain variability between sampling periods, but they should not be used as an analytical tool in the strictest sense (Bowles et al. 2008).



Measuring discharge at Blue Spring, Ozark National Scenic Riverways, Missouri.

The state of Missouri does not have spring specific surface water quality standards. Because the springs we sampled are much cooler than surface fed streams and are more consistent with coldwater habitats, we have opted here to use the Missouri coldwater standards as a basis for comparing water quality (Missouri Department of Natural Resources 2014).

Habitat

Habitat data were collected at three equally spaced sample cells along each transect ($n = 33$; Figure 2) and included both quantitative and qualitative measures. Current velocity (m/second) and depth (cm) were measured in the middle of each 1-m² sample cell. Percent embeddedness, periphyton, filamentous algae, aquatic vegetation, deposition, and organic material were estimated within the sampling cell as percentage categories (Table 2). Dominant substrate size was visually estimated based on the examination of three randomly selected substrate pieces collected from within the sampling cell. The Wentworth scale (Wentworth 1922) was used for visually estimating substrate size. In-stream habitat data were recorded as percentage categories and analyzed as midpoints of each category.

Table 2. Habitat cover value scale used for assessing coverage of in-stream and fish cover habitat variables.

Cover Class Code	Range of Cover (%)
4	>75
3	40-75
2	10-40
1	<10
0	0

Analysis

Because communities are not static, in long-term monitoring we are not interested in testing trivial null hypotheses of no change, but rather in documenting the magnitude of change, and determining biological importance (Bowles et al. 2008). Because sample size is still small ($n = 10$ or fewer years) for this data set, only descriptive statistics are presented in this report.

Aquatic invertebrate diversity was assessed using three measures: taxa richness (S), Simpson's diversity index (D), and the Shannon diversity index (H). Taxa richness is calculated as the total number of invertebrate taxa recorded per transect and includes

all taxa in the estimate. Simpson's diversity index (D) is a dominance index because it weights toward the abundance of the most common taxa. It gives the probability of any two individuals drawn at random from an infinitely large community belonging to different taxa (McCune et al. 2002). Shannon's diversity index accounts for both abundance and evenness of the taxa present, and it is more robust when all species are equally abundant or have high evenness. Diversity measures were calculated for each sample and then averaged across the sample reach ($n = 5$ samples).

To accurately reflect diversity within a single community, it is best to use all three diversity measures (Joust 2006). At the most basic level of species diversity, taxa richness provides a total number of distinct taxa sampled per unit area. Richness is insensitive to taxa abundance. Therefore, a single individual taxon occurring only once in a community is treated the same as a taxon with thousands of individuals in the community. This measure is an indicator of taxa diversity but does not provide any information about the composition of taxa within the community. Shannon diversity index weights species by their abundance. It is an intermediate between taxa richness and Simpson's diversity index in its sensitivity to rare taxa. Therefore, this diversity measure provides information on both the count of unique taxa and their abundance or density in the community.

Simpson's diversity index goes one-step further by disproportionately favoring dominant taxa based on taxa abundance and is little affected by gain or loss of rare taxa.

Shannon and Simpson's diversity index values are converted to effective number of taxa for each community (H_e and D_e , respectively; Hill 1973; Bowles et al. 2008). This allows both diversity measures to be compared directly to taxa richness of the sites within and among sample years based on count of distinct taxa in the community (Joust 2006). Dominance takes into account taxa abundance and evenness of taxa distribution in the community. The degree of taxa dominance in the community is reflected by the degree that taxa richness of the site is greater than the effective number of taxa for each community based on the Simpson's and Shannon's diversity indices ($S > H_e > D_e$) when evenness remains constant in a single community. The difference in number of taxa between the diversity measures reflects both how each metric considers uncommon taxa and how taxa diversity is partitioned within the community among years. If all taxa occurred in equal abundance in the community within and among sample years then $S = H_e = D_e$. Effective number of species for each diversity measure therefore reflects the number of taxa found in a similar community when all taxa occur in equal density.

Results

Aquatic Invertebrates

Invertebrate assemblages among the springs include more than 100 taxa (Appendix 1). Aquatic invertebrate communities within each spring were dynamic among sampling years, and mean taxa richness was relatively low among all springs. Effective numbers of taxa (S , H_e , and D_e) were generally consistent among years for all springs, and given the disparity in those three values for all sites, it shows some communities had higher diversity than others. EPT was relatively low for all springs but the sensitive caddisfly genus, *Lepidostoma* (tolerance value=1) was among the most

dominant taxa occurring in all of the springs. Similarly, mean HBI was less than or equal to 5.93 with HBI values of 5.5 or less considered generally good. Percent intolerant taxa on average made up approximately 25 to 50 percent of the benthic communities. The percent dominant taxa (based on the top three most numerous taxa) typically comprised about 70% or greater of the community. Other common taxa occurring in samples included spring snail (*Amnicola*), water mites (“Hydracarina”), midges (Chironomidae), and amphipods (*Hyaella azteca*, *Crangonyx*, *Gammarus*).



Collecting an aquatic invertebrate sample at Alley Spring, Ozark National Scenic Riverways, Missouri.

Alley Spring

Mean taxa richness for Alley Spring was 20.3 (15.6-27.0), and H_e and D_e were 7.2 (5.1-8.3) and 5.1 (3.2-6.6), respectively (Figure 3, top). Mean EPT richness was 8.7 (6.2-11.0). Taxa and EPT richness for Alley

Spring were highest among all springs. Mean HBI was low 3.8 (2.9-4.3) and never exceeded 4.3 in any year, indicating good conditions (Figure 3, middle). Mean percent intolerant taxa was 41.8 (26.7-57.1), while mean percent dominant taxa was 70.1 (64.6-79.9; Figure 3, bottom).

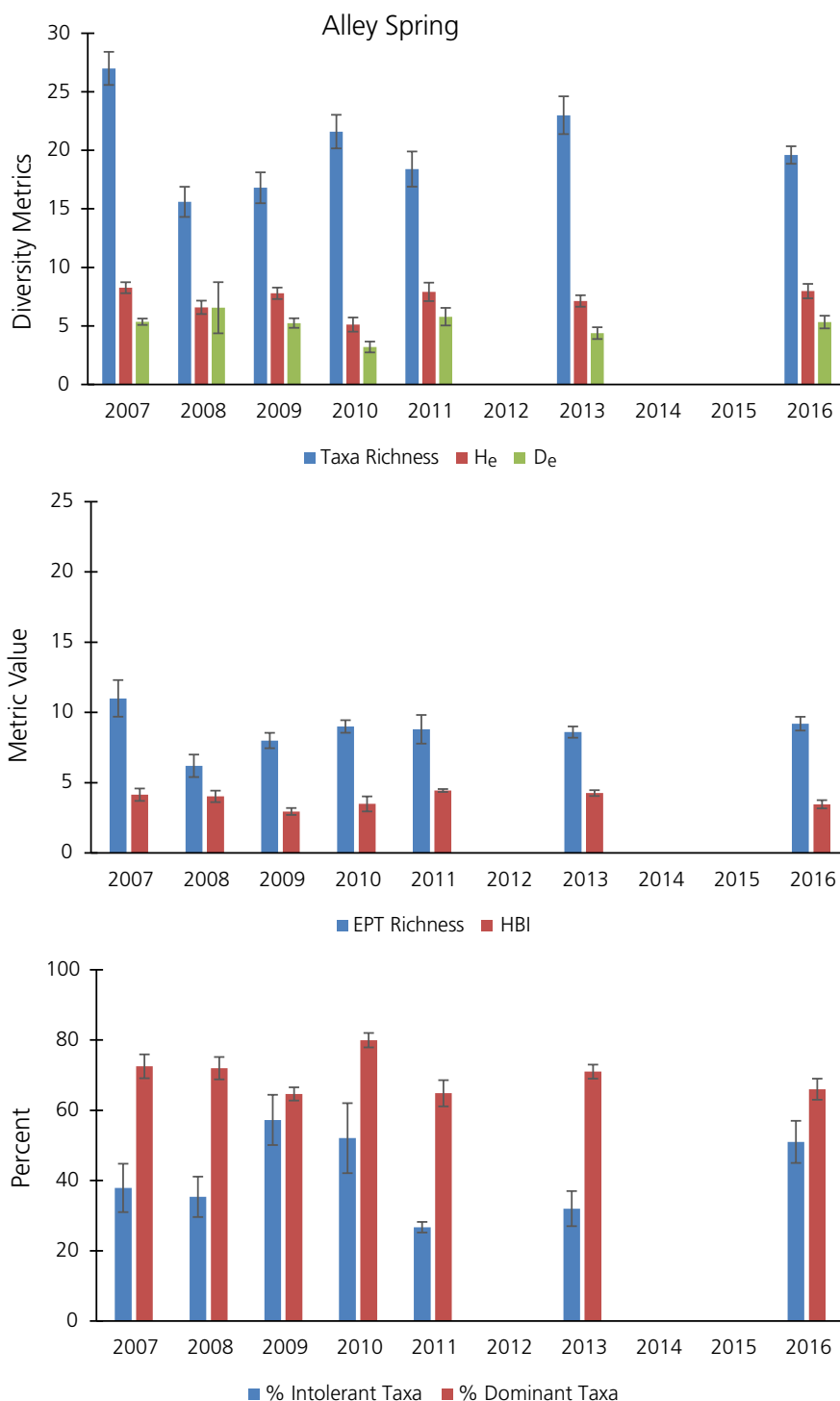


Figure 3. Community diversity metrics for aquatic invertebrates collected at Alley Spring, Ozark National Scenic Riverways, Missouri, 2007-2016. H_e = Shannon's diversity index effective number, D_e = Simpson's diversity index effective number. Values are means and error bars represent one standard error.

Big Spring

Mean taxa richness for Big Spring was 12.1 (9.8-14.4), which was lowest among all springs (Figure 4, top). Mean H_e was 5.2 (4.7-5.7), and mean D_e was 3.8 (2.9-4.5). Few EPT taxa were present in Big Spring (mean

= 2.9, 1.8-3.6), but mean HBI was relatively low at 4.3 (3.4-5.3) indicating good water quality conditions (Figure 4, middle). Mean percent intolerant taxa was 36.4 (13.5-56.0) and mean percent dominant taxa was 78.5 (75.0-81.4; Figure 4, bottom).

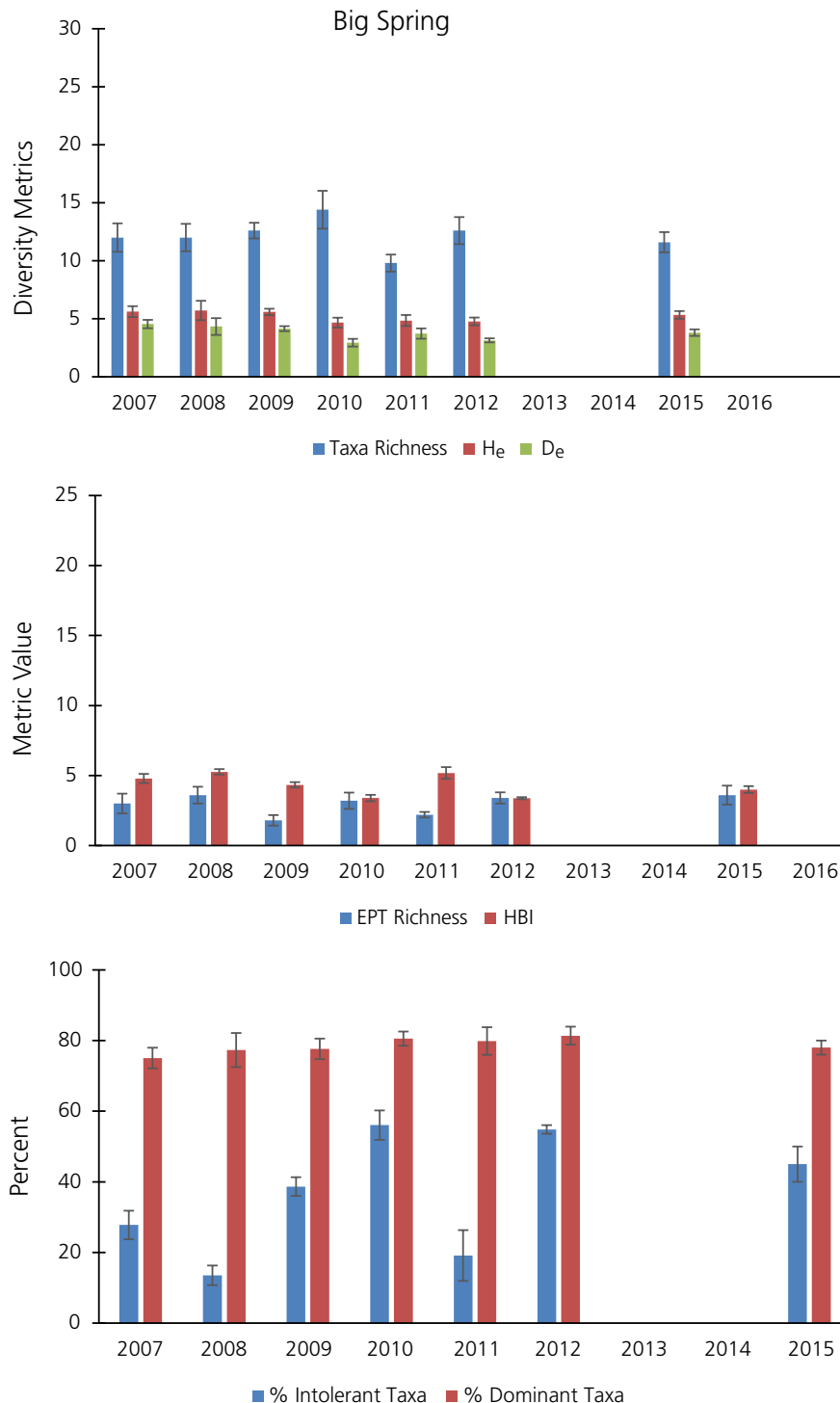


Figure 4. Community diversity metrics for aquatic invertebrates collected at Big Spring, Ozark National Scenic Riverways, Missouri, 2007-2016. H_e = Shannon's diversity index effective number, D_e = Simpson's diversity index effective number. Values are means and error bars represent one standard error.

Blue Spring

Mean taxa richness for Blue Spring was 14.3 (12.4-18.4), while H_e and D_e were 5.4 (5.2-5.7) and 4.1 (3.9-4.5), respectively (Figure 5, top). Blue spring also had a relatively low mean EPT of 3.6 (2.6-4.8)

and low HBI at 4.4 (3.8-4.8; Figure 5, middle). Mean percent intolerant taxa was 31.6 (22.6-43.0) and mean percent dominant taxa was 76.9 (72.5-80.0; Figure 5, bottom).

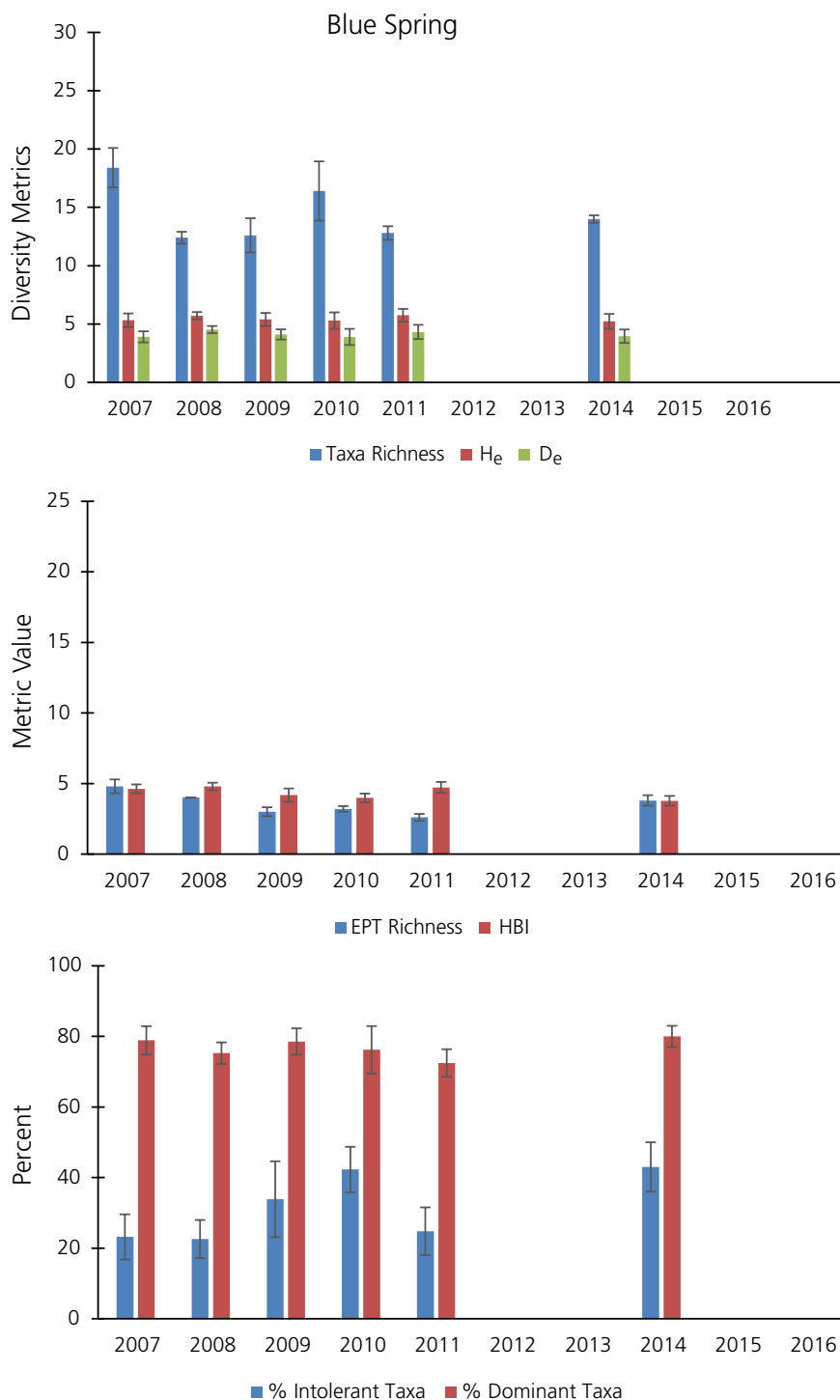


Figure 5. Community diversity metrics for aquatic invertebrates collected at Blue Spring, Ozark National Scenic Riverways, Missouri, 2007-2016. H_e = Shannon's diversity index effective number, D_e = Simpson's diversity index effective number. Values are means and error bars represent one standard error.

Pulltite Spring

Mean taxa richness for Pulltite Spring was the second highest after Alley Spring at 16.7 (13.6-20.6) H_e was 5.7 (4.7-6.7), while D_e was 4.2 (3.5-4.8; Figure 6, top).

Mean EPT was 6.4 (5.2-7.8) and HBI was 5.5 (4.9-5.7; Figure 6, middle). Mean percent intolerant taxa was 11.4 (4.4-17.0) and mean percent dominant taxa was 74.2 (69.4-78.0; Figure 6, bottom).

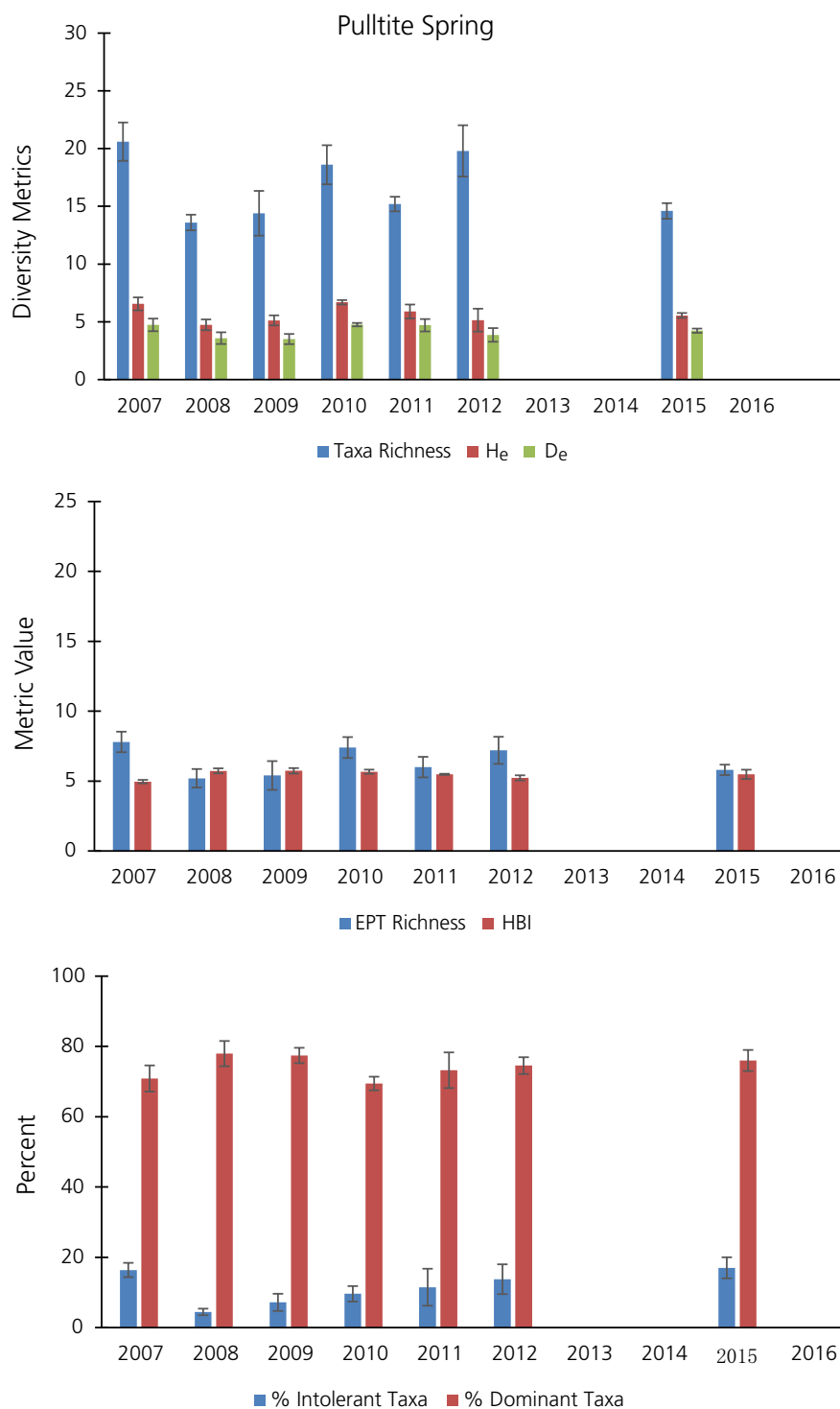


Figure 6. Community diversity metrics for aquatic invertebrates collected at Pulltite Spring, Ozark National Scenic Riverways, Missouri, 2007-2016. H_e = Shannon's diversity index effective number, D_e = Simpson's diversity index effective number. Values are means and error bars represent one standard error.

Round Spring

Mean taxa richness for Round Spring was 15.7 (12.6-19.2), H_e was 6.5 (5.5-7.4) and D_e was 4.9 (3.8-5.7; Figure 7, top). Mean EPT 3.9 (2.6-5.2) was similar to that for most other springs, except Alley Spring, and

a similar response was observed for mean HBI at 5.2 (4.4-5.9; Figure 7, middle). Mean percent intolerant taxa was 38.0 (9.3-25.2), while mean percent dominant taxa was 73.0 (64.8-76.4; Figure 7, bottom).

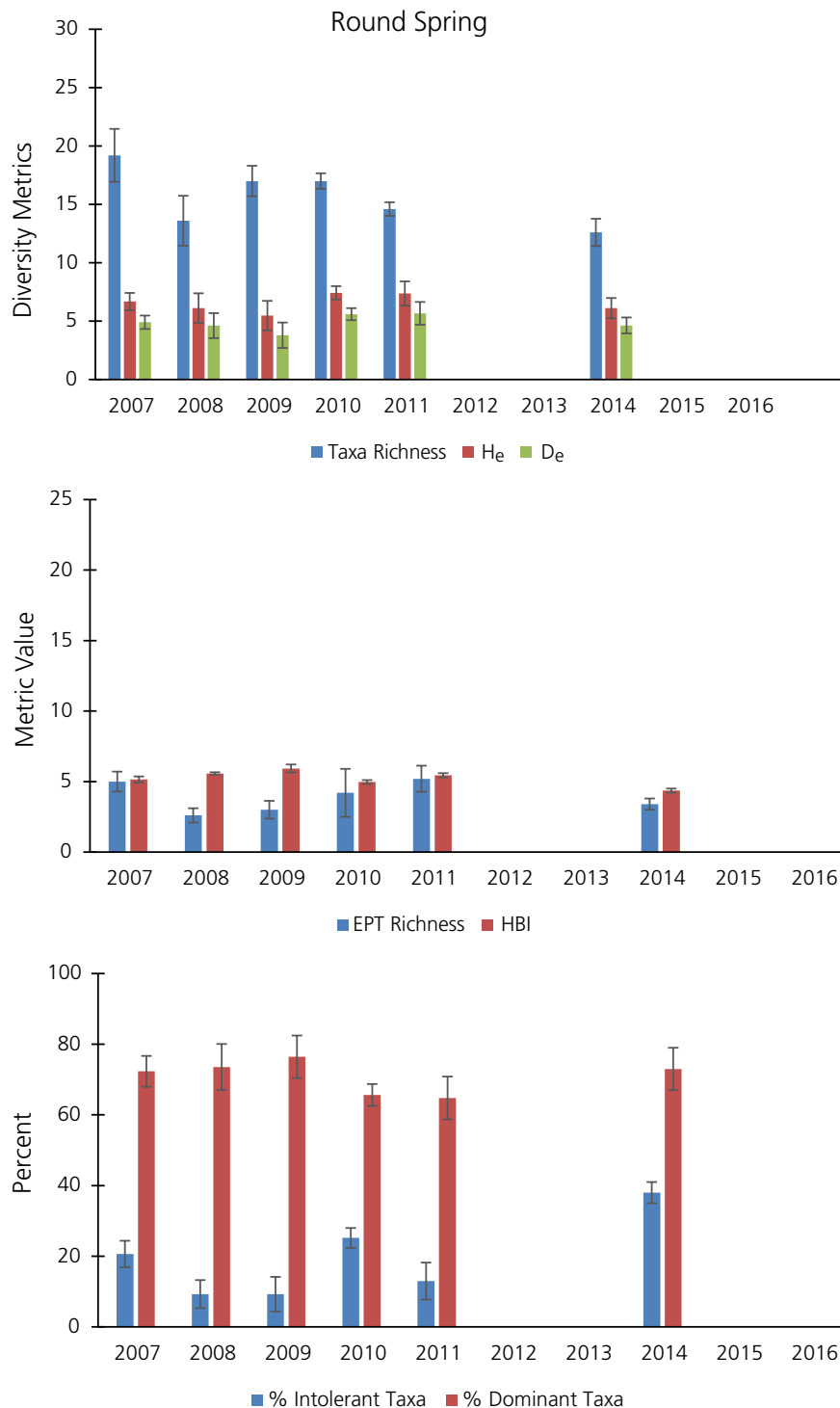


Figure 7. Community diversity metrics for aquatic invertebrates collected at Round Spring, Ozark National Scenic Riverways, Missouri, 2007-2016. H_e = Shannon's diversity index effective number, D_e = Simpson's diversity index effective number. Values are means and error bars represent one standard error.

Welch Spring

Even though Welch Spring has a much shorter spring-run, the invertebrate community values measured (Figure 8) were similar to those of the other springs. Mean taxa richness was 15.9

(14.0-18.3), H_e was 5.2 (2.7-7.0), and D_e was 3.6 (1.7-4.9). Mean EPT was 5.5 (4.7-5.7), while mean HBI was 5.5 (4.5-5.9). Mean percent intolerant taxa was 16.2 (4.7-32.1) and mean percent dominant taxa was 77.8 (69.0-89.9).

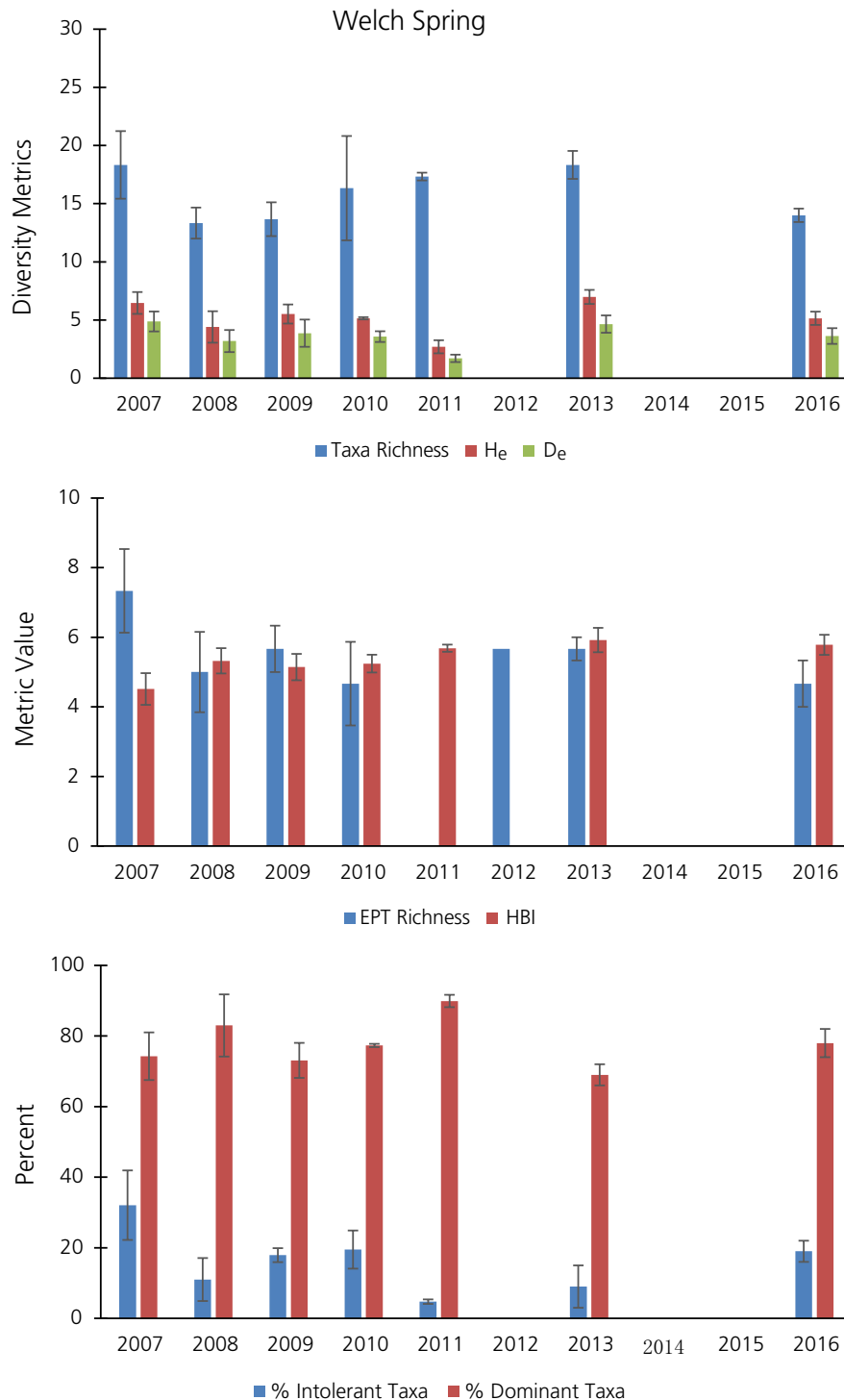


Figure 8. Community diversity metrics for aquatic invertebrates collected at Welch Spring, Ozark National Scenic Riverways, Missouri, 2007-2016. H_e = Shannon's diversity index effective number, D_e = Simpson's diversity index effective number. Values are means and error bars represent one standard error.

Phillips Spring

Mean taxa richness for Phillips Spring was 14.5 (13.0-16.6), H_e was 6.7 (6.1-7.0), and D_e was 4.8 (4.3-5.2; Figure 9, top). Mean EPT was 4.3 (3.8-5.0),

while mean HBI was 4.4 (4.3-4.5; Figure 9, middle). Mean percent intolerant taxa was 37.1 (25.2-47.0) and mean percent dominant taxa was 69.1 (66.0-72.4; Figure 9, bottom).



Figure 9. Community diversity metrics for aquatic invertebrates collected at Phillips Spring, Ozark National Scenic Riverways, Missouri, 2011, 2013, and 2016. H_e = Shannon's diversity index effective number, D_e = Simpson's diversity index effective number. Values are means and error bars represent one standard error.

Water Quality

Water quality data were similar among springs and years (Appendix 2). In all instances, water quality for each spring met Missouri state standards for cold water habitats (Table 3). No further analysis of the water quality data is presented here.

Table 3. Acceptable ranges for water quality parameters in Missouri Ozarks coldwater streams (Brown and Czarnecki undated; Missouri Department of Natural Resources 2014).

Water Quality Parameter	Acceptable Range
Temperature	<20 °C
Dissolved Oxygen	>6 mg/liter
Specific Conductance	100-400 µS/cm
pH	6.5-9.0
Turbidity	Variable, but generally <10 NTU dry weather

Habitat

Water depth and velocity varied among springs, and to a lesser extent among years, but the high degree of overlap in standard errors of the mean within individual springs in most years suggest these differences would not be significant (Table 4). Current velocity among the springs was high and was consistent with the run habitat that dominant these systems.

Substrate among the springs varied considerably (Table 4). The substrate for Alley, Blue, Pulltite and

Welch springs was predominantly large pebble-small cobble (32-90 mm). The substrate of Big and Round springs generally contained smaller mean substrate sizes compared to the other springs, as well as a wide range of substrate sizes ranging from sands and gravels to cobble and boulders. Embeddedness was generally around 25-30% for most springs, except for Big and Round springs, where the small substrate sizes in those two springs resulted in high embeddedness.

Mean in-stream habitat cover was dynamic among springs and sampling years (Table 4). Organic debris among springs was usually low ($\leq 20\%$), except for Round and Pulltite Springs, where organic debris ranged from 30-40% of the sampling area. The organic debris levels for Round Spring likely are due to the lower gradient and slower flows associated with this system as compared to the other springs. Periphyton generally was less than 25%. Filamentous green algae generally were around 25% or less of cover and included *Batrachospermum* (Rhodophyta), *Cladophora*, and *Vaucheria* (Chlorophyta). Aquatic vegetation was well represented in sample cells, typically exceeding 60% cover, but percentages varied widely across years. Canopy cover for all of the springs was less than 40%.

Discharge varied among springs and years with Big Spring consistently having the highest flow and Round and Phillips springs consistently having the lowest flows among years (Table 5).

Table 4. Habitat metrics for aquatic invertebrate samples collected at springs located at Ozark National Scenic Riverways. N = 11 each year. Values are means with standard errors in parentheses.

Spring	Year	Depth (cm)	Velocity (m/sec)	Substrate Size (mm)	Embeddedness (%)	Organic Debris (%)	Periphyton (%)	Filamentous Algae (%)	Aquatic Vegetation (%)	Canopy Cover (%)
Alley	2007	59.82 (6.33)	0.43 (0.04)	65.00 (30.97)	32.05 (2.85)	13.00 (4.90)	25.00 (0.00)	11.00 (5.79)	75.50 (7.35)	11.89 (2.37)
	2008	58.61 (4.35)	0.57 (0.07)	64.18 (5.28)	25.38 (1.21)	17.88 (2.64)	25.00 (0.00)	24.17 (1.49)	30.91 (4.62)	17.20 (3.99)
	2009	53.24 (4.12)	0.58 (0.03)	58.82 (7.16)	35.08 (3.99)	19.92 (1.68)	23.56 (1.57)	4.39 (1.51)	58.11 (4.58)	15.95 (3.20)
	2010	57.06 (4.78)	0.51 (0.07)	53.11 (5.28)	37.80 (2.85)	19.70 (2.92)	25.00 (0.00)	22.01 (2.55)	67.20 (3.67)	42.84 (6.89)
	2011	62.73 (5.59)	0.65 (0.08)	52.65 (5.60)	27.12 (2.24)	15.91 (2.25)	25.00 (0.00)	25.95 (3.58)	51.29 (5.30)	41.44 (5.49)
	2012	53.27 (5.48)	0.45 (0.06)	61.46 (9.88)	28.94 (2.20)	22.88 (3.45)	24.39 (0.61)	5.45 (2.97)	76.44 (3.51)	40.23 (7.86)
	2013	57.94 (5.55)	0.47 (0.09)	54.45 (6.22)	35.15 (2.81)	18.11 (5.98)	24.39 (0.61)	24.81 (2.78)	67.88 (4.07)	55.04 (6.56)
	2014	58.15 (6.00)	0.55 (0.08)	51.63 (3.23)	32.88 (2.57)	25.23 (2.34)	23.79 (0.81)	23.03 (2.47)	83.79 (2.09)	37.42 (7.75)
	2015	54.06 (4.74)	0.57 (0.08)	43.20 (6.66)	34.24 (2.76)	21.82 (4.45)	25.00 (0.00)	17.92 (6.22)	69.62 (3.60)	46.70 (11.35)
	2016	61.21 (4.31)	0.52 (0.08)	59.51 (6.42)	37.42 (3.41)	20.76 (3.02)	24.55 (1.93)	25.98 (3.47)	54.39 (6.37)	28.18 (8.53)
Big	2007	73.55 (6.02)	0.42 (0.06)	92.65 (52.62)	51.00 (6.50)	n/a	0.00 (0.00)	33.50 (14.04)	21.00 (4.00)	21.00 (4.00)
	2008	79.36 (3.84)	0.41 (0.05)	28.47 (7.42)	49.17 (5.87)	25.53 (1.85)	21.06 (1.46)	16.97 (4.15)	54.66 (6.70)	20.53 (5.18)
	2009	83.64 (2.87)	0.33 (0.05)	55.54 (23.42)	54.92 (5.32)	20.76 (3.38)	16.52 (2.22)	7.20 (2.05)	74.55 (3.66)	19.32 (3.93)
	2010	84.52 (3.88)	0.36 (0.05)	28.68 (6.38)	50.76 (5.15)	19.92 (2.40)	21.97 (1.38)	10.76 (3.32)	66.29 (3.78)	25.91 (5.95)
	2011	80.48 (3.84)	0.49 (0.04)	27.59 (6.71)	50.61 (4.90)	18.64 (2.01)	23.56 (2.21)	18.03 (2.36)	47.95 (5.12)	36.17 (7.61)
	2012	63.58 (2.73)	0.38 (0.04)	28.31 (8.07)	55.38 (5.27)	27.35 (1.75)	21.36 (1.65)	3.64 (2.25)	60.45 (5.29)	55.72 (6.82)
	2013	74.27 (3.02)	0.38 (0.05)	31.36 (7.62)	49.77 (4.78)	31.06 (3.00)	24.77 (1.37)	0.45 (0.45)	52.65 (3.90)	36.02 (8.57)

Table 4 (continued). Habitat metrics for aquatic invertebrate samples collected at springs located at Ozark National Scenic Riverways. N = 11 each year. Values are means with standard errors in parentheses.

Spring	Year	Depth (cm)	Velocity (m/sec)	Substrate Size (mm)	Embeddedness (%)	Organic Debris (%)	Periphyton (%)	Filamentous Algae (%)	Aquatic Vegetation (%)	Canopy Cover (%)
Big, cont.	2014	77.97 (3.659)	0.46 (0.04)	36.65 (9.77)	48.11 (3.44)	25.91 (2.09)	21.36 (1.38)	19.32 (5.20)	66.97 (3.72)	42.99 (10.53)
	2015	88.70 (2.80)	0.38 (0.03)	39.26 (10.70)	45.68 (6.13)	25.83 (3.81)	28.45 (1.83)	14.70 (3.25)	49.51 (6.42)	44.62 (10.04)
	2016	71.76 (3.11)	0.49 (0.05)	36.30 (12.77)	49.09 (5.53)	20.45 (3.61)	23.26 (1.92)	17.42 (2.77)	32.54 (5.77)	29.92 (10.74)
Blue	2007	34.15 (4.91)	0.48 (0.06)	69.71 (16.13)	31.50 (6.50)	21.00 (4.00)	25.00 (0.00)	11.00 (5.79)	63.00 (11.63)	n/a
	2008	38.45 (4.20)	0.61 (0.06)	64.41 (8.29)	30.08 (5.77)	9.85 (2.03)	24.24 (0.76)	24.62 (5.99)	63.26 (5.26)	21.52 (4.49)
	2009	35.67 (5.13)	0.59 (0.06)	108.87 (16.96)	30.54 (6.04)	29.47 (4.63)	21.36 (2.08)	16.97 (3.06)	73.86 (3.38)	18.11 (1.73)
	2010	41.73 (8.60)	0.58 (0.11)	80.15 (14.37)	27.95 (2.95)	6.82 (1.82)	15.91 (3.15)	8.64 (3.24)	65.68 (4.23)	20.45 (8.67)
	2011	28.55 (9.49)	0.50 (0.11)	49.46 (13.47)	42.50 (6.58)	21.36 (2.44)	26.82 (5.31)	36.82 (4.94)	65.00 (8.50)	37.50 (11.59)
	2012	33.64 (7.14)	0.49 (0.12)	97.56 (20.77)	31.82 (6.64)	12.27 (3.04)	23.18 (1.82)	25.23 (7.03)	68.18 (6.25)	39.32 (12.63)
	2013	33.00 (4.43)	0.42 (0.09)	78.88 (17.65)	33.64 (6.14)	20.00 (6.21)	29.09 (4.60)	18.18 (6.68)	68.18 (6.25)	29.09 (10.98)
	2014	48.63 (6.23)	0.21 (0.04)	62.69 (10.31)	30.91 (3.96)	17.73 (3.04)	23.18 (1.82)	25.68 (6.88)	71.14 (4.72)	18.64 (10.51)
	2015	33.36 (4.14)	0.66 (0.10)	112.91 (22.55)	28.86 (6.14)	17.05 (5.01)	25.00 (0.00)	29.77 (8.34)	57.05 (5.96)	45.00 (11.91)
	2016	30.36 (2.72)	0.82 (0.12)	81.29 (15.41)	30.68 (5.68)	14.09 (3.15)	19.09 (3.08)	22.05 (4.66)	60.00 (5.03)	27.05 (11.91)
Pulltite	2007	29.58 (6.09)	0.30 (0.05)	61.18 (21.71)	31.50 (6.50)	13.00 (4.90)	25.00 (0.00)	16.50 (11.34)	81.50 (6.00)	n/a
	2008	36.85 (5.07)	0.52 (0.07)	95.30 (11.80)	27.73 (3.76)	14.70 (2.08)	23.48 (1.52)	23.26 (3.32)	61.74 (4.03)	24.47 (7.34)
	2009	36.06 (7.31)	0.53 (0.06)	69.32 (9.11)	35.15 (4.93)	17.05 (3.89)	22.58 (1.36)	15.68 (4.04)	67.20 (4.61)	31.67 (7.36)
	2010	36.58 (6.62)	0.54 (0.08)	86.64 (16.87)	38.18 (4.03)	12.05 (2.45)	20.45 (1.44)	16.74 (3.49)	76.82 (2.94)	29.62 (7.62)

Table 4 (continued). Habitat metrics for aquatic invertebrate samples collected at springs located at Ozark National Scenic Riverways. N = 11 each year. Values are means with standard errors in parentheses.

Spring	Year	Depth (cm)	Velocity (m/sec)	Substrate Size (mm)	Embeddedness (%)	Organic Debris (%)	Periphyton (%)	Filamentous Algae (%)	Aquatic Vegetation (%)	Canopy Cover (%)
Pulltite, cont.	2011	49.41 (7.31)	1.40 (0.82)	40.68 (4.77)	24.47 (1.53)	45.38 (6.88)	27.05 (3.32)	50.15 (3.51)	21.29 (3.99)	29.62 (7.62)
	2012	27.82 (6.13)	0.40 (0.06)	71.59 (13.86)	40.45 (3.84)	26.36 (1.53)	23.79 (1.21)	28.41 (4.23)	72.65 (3.77)	50.45 (8.14)
	2013	36.58 (4.63)	0.48 (0.09)	30.74 (3.34)	39.39 (4.04)	22.05 (3.05)	27.88 (2.05)	15.87 (2.86)	59.39 (3.88)	45.53 (7.26)
	2014	30.73 (4.84)	0.40 (0.05)	88.28 (18.37)	37.50 (3.68)	25.30 (2.79)	22.58 (1.63)	17.05 (2.90)	75.38 (4.59)	56.10 (6.39)
	2015	40.55 (6.35)	0.75 (0.10)	38.01 (8.86)	38.33 (5.19)	18.33 (3.95)	22.58 (1.01)	17.73 (2.61)	59.62 (4.45)	55.30 (8.34)
	2016	44.27 (6.86)	0.72 (0.07)	85.95 (16.61)	33.64 (5.58)	11.06 (1.84)	19.85 (1.87)	13.83 (5.24)	63.11 (4.62)	27.61 (8.72)
Round	2007	37.88 (4.71)	0.17 (0.02)	32.18 (8.88)	69.50 (7.35)	44.50 (7.96)	25.00 (0.00)	6.00 (4.85)	32.50 (14.58)	n/a
	2008	45.03 (5.90)	0.70 (0.56)	26.33 (9.86)	49.32 (5.89)	30.33 (3.51)	19.17 (2.79)	21.74 (4.66)	59.24 (6.49)	16.44 (6.39)
	2009	56.64 (3.06)	0.34 (0.05)	11.94 (4.05)	70.68 (5.46)	29.02 (6.07)	15.15 (1.91)	10.83 (2.52)	50.91 (4.70)	19.92 (6.80)
	2010	43.70 (4.04)	0.10 (0.01)	17.22 (5.90)	62.05 (6.01)	19.77 (3.37)	12.27 (1.90)	15.15 (1.96)	56.82 (2.37)	36.70 (7.87)
	2011	41.48 (5.03)	0.12 (0.02)	26.49 (13.18)	67.05 (5.64)	27.05 (2.20)	26.93 (4.05)	15.72 (5.12)	55.95 (4.79)	26.10 (3.91)
	2012	33.18 (3.85)	0.36 (0.26)	14.25 (9.53)	69.89 (7.92)	35.80 (4.64)	12.47 (2.41)	6.36 (2.87)	64.06 (7.39)	41.87 (8.12)
	2013	43.79 (3.89)	0.13 (0.02)	26.96 (13.07)	62.42 (5.07)	27.27 (2.70)	20.45 (3.26)	44.32 (6.22)	71.2 (2.73)	43.75 (8.75)
	2014	43.79 (2.86)	0.10 (0.02)	23.68 (11.96)	66.36 (4.57)	38.79 (4.75)	19.51 (3.29)	11.48 (4.45)	66.97 (5.05)	41.74 (10.14)
	2015	54.39 (3.13)	0.24 (0.03)	27.93 (17.29)	68.86 (7.36)	38.79 (2.57)	23.56 (5.35)	15.11 (4.00)	70.98 (5.56)	47.84 (9.51)
	2016	52.61 (3.44)	0.16 (0.03)	28.37 (15.91)	62.27 (3.60)	30.30 (5.53)	19.24 (2.01)	10.61 (3.12)	71.82 (3.21)	26.78 (8.99)

Table 4 (continued). Habitat metrics for aquatic invertebrate samples collected at springs located at Ozark National Scenic Riverways. N = 11 each year. Values are means with standard errors in parentheses.

Spring	Year	Depth (cm)	Velocity (m/sec)	Substrate Size (mm)	Embeddedness (%)	Organic Debris (%)	Periphyton (%)	Filamentous Algae (%)	Aquatic Vegetation (%)	Canopy Cover (%)
Welch	2007	65.11 (6.16)	0.59 (0.31)	44.65 (18.91)	34.03 (4.78)	8.33 (8.33)	25.00 (0.00)	3.33 (1.67)	77.50 (10.00)	2.78 (2.78)
	2008	67.67 (11.78)	0.51 (0.35)	131.22 (43.82)	33.47 (15.07)	19.72 (7.46)	28.47 (1.84)	20.00 (5.00)	40.97 (9.14)	6.39 (6.39)
	2009	59.33 (7.37)	0.49 (0.12)	125.84 (43.52)	32.50 (5.09)	19.72 (8.93)	24.17 (3.15)	12.22 (5.30)	63.89 (3.61)	1.67 (0.96)
	2010	65.22 (9.17)	0.36 (0.26)	107.66 (57.70)	38.06 (11.08)	15.28 (5.28)	18.33 (6.67)	27.08 (7.65)	60.00 (9.29)	11.67 (6.67)
	2011	112.82 (54.18)	0.23 (0.17)	47.78 (13.75)	25.56 (12.03)	13.33 (7.26)	30.42 (5.42)	73.61 (13.89)	25.28 (6.02)	0.00 (0.00)
	2012	56.89 (12.39)	0.28 (0.15)	127.23 (39.90)	39.44 (9.86)	29.17 (10.10)	25.56 (5.28)	5.56 (3.38)	70.28 (9.08)	19.17 (19.17)
	2013	55.44 (11.09)	0.51 (0.14)	118.51 (52.31)	31.94 (6.94)	17.50 (6.29)	35.83 (10.83)	15.00 (5.77)	80.83 (6.67)	13.33 (7.26)
	2014	58.22 (12.23)	0.35 (0.21)	98.90 (30.72)	40.56 (9.41)	24.72 (12.08)	25.00 (0.00)	26.94 (15.76)	67.08 (6.14)	46.39 (23.26)
	2015	64.00 (11.03)	0.36 (0.22)	51.67 (36.83)	48.61 (14.73)	23.33 (6.99)	24.17 (6.99)	3.33 (1.67)	71.67 (11.21)	33.75 (17.72)
	2016	77.22 (20.63)	0.37 (0.23)	124.78 (70.32)	49.44 (15.26)	7.22 (2.22)	20.56 (4.44)	6.67 (4.41)	60.28 (9.25)	8.33 (8.33)
Phillips	2011	31.42 (4.21)	0.35 (0.03)	21.44 (3.53)	47.58 (4.90)	25.76 (3.85)	24.77 (1.37)	15.87 (2.36)	20.76 (1.63)	60.00 (5.22)
	2012	28.58 (3.56)	0.25 (0.04)	22.75 (3.23)	47.35 (4.61)	34.77 (2.64)	25.00 (0.00)	14.17 (3.27)	31.25 (4.36)	62.95 (6.78)
	2013	31.64 (3.83)	0.42 (0.05)	21.19 (3.01)	51.06 (4.15)	30.57 (3.39)	23.79 (0.81)	0.45 (0.45)	27.61 (2.48)	64.32 (5.53)
	2014	32.00 (4.00)	0.38 (0.05)	28.62 (4.63)	43.48 (4.56)	28.26 (4.60)	24.39 (0.61)	12.88 (3.18)	28.07 (3.11)	78.33 (2.88)
	2015	41.88 (4.32)	0.45 (0.06)	25.12 (3.15)	37.73 (2.39)	17.27 (2.64)	25.00 (0.00)	15.27 (3.35)	24.09 (3.36)	75.87 (4.39)
	2016	36.21 (3.46)	0.30 (0.06)	47.12 (13.45)	33.86 (2.45)	8.64 (1.38)	24.39 (0.61)	7.42 (2.19)	21.52 (2.50)	52.20 (10.57)

Table 5. Discharge (m³/sec) for springs located at Ozark National Scenic Riverways, 2007-2016. nm = not measured.

Year	Alley Spring	Biga Spring	Blue Spring	Pulltite Spring	Round Spring	Welch Spring	Phillips Spring
2007	3.05	13.93	2.88	1.11	0.63	4.01	nm
2008	3.62	13.54	3.13	2.21	0.88	6.65	nm
2009	3.80	11.78	3.97	1.63	2.99	8.41	nm
2010	3.94	13.03	3.40	1.44	0.86	7.19	nm
2011	3.79	14.75	3.14	1.84	0.87	3.88 (est.)	0.61
2012	1.23	9.85	2.19	0.37	0.50	2.00	0.58
2013	3.19	13.79	4.12	2.42	0.86	n/a	1.08
2014	2.47	13.11	3.33	1.05	0.48	6.10	0.70
2015	2.84	18.43	4.59	3.50	1.91	8.00	1.26
2016	5.78	10.59	6.18	2.77	1.07	6.59	0.91

Discussion

Habitat conditions within a spring depend on groundwater sources and a matrix of other factors (Williams and Danks 1991). Because of their unique and independent sources, springs typically have a mosaic structure, a high degree of individuality, and typically an azonal character attributed to their physiochemical stability (Cantonati et al. 2006). The monitoring results presented here support that assessment.

The invertebrate fauna in all of the springs monitored at Ozark National Scenic Riverways is dominated by environmentally sensitive taxa (Barbour et al. 1999; Appendix 1). Although the percentage of intolerant invertebrate taxa among springs was moderate ($\leq 40\%$) these taxa typically were the most numerically dominant accounting for at least 70% of the total density. This finding was also demonstrated in the relatively low HBI scores for each site. The dominance of intolerant taxa, and mainly representatives

of the caddisfly genus, *Lepidostoma* (tolerance value = 1), occurring in the springs indicates their respective water quality conditions are good. Although these findings indicate the water and habitat conditions in the springs are high quality, there presently are insufficient data from which to base any specific conclusions on invertebrate community structure and dynamics. Additional monitoring and trend analysis may allow insight into possible patterns that may exist in community structure in these springs.

The data presented here reflect the broad natural habitat diversity and physical and chemical stability in these springs. Collecting and analyzing additional monitoring data are required to determine the importance of habitat and water quality factors on aquatic invertebrate community structure and help elucidate other unknown factors that might be influencing them.



Downstream view from Blue Spring, Ozark National Scenic Riverways, Missouri.

Literature Cited

- Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid bioassessment protocols for use in streams and Wadeable rivers: Periphyton, benthic macroinvertebrate, and fish. 2nd ed. EPA 841-B-99-002, U.S. Environmental Protection Agency, Washington, DC.
- Benac, D., and S. Flader. 2004. History of Missouri forests in the era of exploitation and conservation. General Technical Report SRS-73. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina, U.S.A.
- Bowles, D. E., H. R. Dodd, M. H. Williams, L. M. Morrison, K. James, M. D. DeBacker, C. E. Ciak, J. A. Hinsey, G. A. Rowell, and J. L. Haack. 2008. Protocol for monitoring spring communities at Ozark National Scenic Riverways, Missouri. Natural Resource Report NPS/HTLN/NRR—2008/029. National Park Service, Fort Collins, Colorado.
- Bowles, D. E., H. R. Dodd, J. A. Hinsey, J. T. Cribbs, and J. A. Luraas. 2011. Spring communities monitoring at Ozark National Scenic Riverways, Missouri: 2007-2009 status report. Natural Resource Technical Report NPS/OZAR/NRTR—2011/511. National Park Service, Fort Collins, Colorado.
- Bowles, D. E., and H. R. Dodd. 2015. Floristics and community ecology of aquatic vegetation occurring in seven large springs at Ozark National Scenic Riverways, Missouri (U.S.A.), 2007–2012. *Journal of the Botanical Institute of Texas* 9:235-249.
- Bowles, D. E., and H. R. Dodd. 2016a. Monitoring Missouri's large springs. *Missouri Natural Areas Newsletter* 16:13-18.
- Bowles, D. E., and H. R. Dodd. 2016b. Aquatic vegetation monitoring in springs at Ozark National Scenic Riverways, 2007-2015. Natural Resource Data Series NPS/OZAR/NRDS—2016/1044. National Park Service, Fort Collins, Colorado.
- Brown, D., and J. Czarnecki. Undated. Missouri streams fact sheet—chemical monitoring. Missouri Department of Conservation. Jefferson City, Missouri.
- Brune, G. 1981. *Springs of Texas*, volume I. Branch-Smith, Inc. Fort Worth, Texas.
- Cantonati, M., R. Gerecke, and E. Bertuzzi. 2006. Springs of the Alps—sensitive ecosystems to environmental change: from biodiversity assessments to long-term studies. *Hydrobiologia* 562:59-96.
- Carter, R. W., and J. Davidian. 1969. General procedure for gaging streams. Book 3, Chapter A6 of *Techniques of water-resources investigations of the United States Geological Survey*. United States Government Printing Office, Washington, DC.
- DeBacker, M. D., D. E. Bowles, H. R. Dodd, and L. W. Morrison. 2011. Five-year review and recommendations for revision of aquatic sampling protocols at Buffalo National River and Ozark National Scenic Riverways. Natural Resource Report NPS/HTLN/NRR—2012/563. National Park Service, Fort Collins, Colorado.
- Duchrow, R. M. 1977. Water quality of the Current, Jacks Fork, Eleven Point, Little Black, and Warm Fork of the Spring River basins of Missouri. Missouri Department of Conservation, Fish and Wildlife Research Center, Columbia, Missouri.
- Erman, N. A., and D. C. Erman. 1995. Spring permanence, Trichoptera species richness, and the role of drought. *Journal of the Kansas Entomological Society* 68:50-64.
- Gibert, J. 1990. Behavior of aquifers concerning contaminants: Differential permeability and importance of the different purification processes. *Water, Science Technology* 22:101-108.
- Hill, M.O. 1973. Diversity and evenness: A unifying notation and its consequences. *Ecology* 54:427-432.
- Hogg, I. D., and D. D. Williams. 1996. Responses of stream invertebrates to a global-warming thermal regime: An ecosystem-level manipulation. *Ecology* 77:395-407.

- Imes, J. L., and B. S. Fredrick. 2002. Using dye-tracing and chemical analyses to determine effects of a wastewater discharge to Jam Up Creek on water quality of Big Spring, southeastern Missouri, 2001. USGS Fact Sheet 103-02. U.S. Geological Survey, Rolla, Missouri.
- Jacobson, R. B., and A. T. Primm. 1997. Historical land-use changes and potential effects on stream disturbance in the Ozark Plateaus, Missouri. U.S. Geological Survey Water-Supply Paper 2494.
- Johnson, T. 2007. Will climate change affect groundwater in the central and west coast basins? Water Replenishment District of Southern California Technical Bulletin 10:1-2.
- Joust, L. 2006. Entropy and diversity. *Oikos* 113: 363-375.
- McCune, B., J. B. Grace, and D. L. Urban. 2002. Analysis of ecological communities. MjM Software Design, Gleneden Beach, Oregon, U.S.A.
- Missouri Department of Natural Resources. 2014. Rules of Department of Natural Resources Division 20—Clean Water Commission, Chapter 7—Water Quality. Jefferson City, Missouri.
- Meinzer, O. E. 1927. Large springs in the United States: U.S. Geological Survey, Water-Supply Paper 557.
- Moulton, S. R. III, J. G. Kennen, R. M. Goldstein, and J. A. Hambrook. 2002. Revised protocols for sampling algal, invertebrate, and fish communities as part of the National Water-Quality Assessment Program. Open-file Report 02-150.
- Mugel, D. N., J. M. Richards, J. M., and J. G. Schumacher. 2009. Geohydrologic investigations and landscape characteristics of areas contributing water to springs, the Current River, and Jacks Fork, Ozark National Scenic Riverways, Missouri, U.S. Geological Survey Scientific Investigations Report 2009-5138.
- Notenboom, J., S. Plenet, and M. Turqin. 1994. Groundwater contamination and its impact on groundwater animals and ecosystems. Pages 477-504 in J. Gibert, D. Danielopol, and J. Stanford, editors, *Groundwater Ecology*. Academic Press, London, England.
- Poff, N. L., M. M. Brinson, and J. W. Day, Jr. 2002. Aquatic ecosystems & global climate change, potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Pew Center on Global Climate Change, Arlington, VA.
- Scott, H. D., and T. H. Udouj. 1999. Spatial and temporal characterization of land-use in the Buffalo National River watershed. *Environmental Conservation* 26:94-101.
- United States Code. 1964. An act to provide for the establishment of the Ozark National Scenic Riverways in the state of Missouri, and for other purposes. Public Law 88-492, § 3, August 27, 78 Stat., pp. 608-610.
- van der Kamp, G. 1995. The hydrogeology of springs in relation to the biodiversity of spring fauna: A review. *Journal of the Kansas Entomological Society Supplement* 68:4-17.
- Vineyard, J. D., G. Feder, L., W. L. Pflieger, and R. G. Lipscomb. 1974. Springs of Missouri with sections on fauna and flora. Water Resources Report No. 29, Missouri Geological Survey and Water Resources, Rolla, Missouri, U.S.A.
- Wentworth, C. K. 1922. A scale of grade and class terms for clastic sediments. *Journal of Geology* 30:377-392.
- Williams, D. D. 1991. The spring as an interface between groundwater and lotic faunas and as a tool in assessing groundwater quality. *Internationale Vereinigung fuer Theoretische und Angewandte Limnologie. Verhandlungen - Internationale Vereinigung fuer Theoretische und Angewandte Limnologie* 24:1621-1624.
- Williams, D. D., and H. Danks. 1991. Arthropods of springs, with particular reference to Canada. *Memoirs of the Entomological Society of Canada* 155:1-217.

Appendix A: List of Collected Aquatic Invertebrates

Table A1. Aquatic invertebrates collected at springs located at Ozark National Scenic Riverways, 2007-2016. Environmentally sensitive taxa have tolerance values of 3 or less. X = present; ud = tolerance value for that species is undetermined.

Phylum	Class	Order	Family	Genus/species	Tolerance Value	Alley	Big	Blue	Phillips	Pulltite	Round	Welch
Annelida	Hirudinea	–	–	–	10	–	–	X	–	–	–	–
Annelida	–	Branchiobdellida	–	–	6	X	–	–	–	–	–	–
Annelida	Oligochaeta	–	–	–	10	X	X	X	X	X	X	X
Arthropoda	Arachnoida	Hydracarina	–	–	5.6	X	X	X	X	X	X	X
Arthropoda	Crustacea	Amphipoda	Crangonyctidae	<i>Crangonyx forbesi</i>	8	X	X	X	X	X	X	X
Arthropoda	Crustacea	Amphipoda	Crangonyctidae	<i>Stygobromus onadagensis</i>	ud	X	–	–	X	X	–	–
Arthropoda	Crustacea	Amphipoda	Gammaridae	<i>Gammarus pseudolimnaeus</i>	6.9	X	X	X	X	X	X	X
Arthropoda	Crustacea	Amphipoda	Hyalellidae	<i>Hyalella azteca</i>	7.9	X	X	X	–	–	X	X
Arthropoda	Crustacea	Copepoda	–	–	–	X	X	–	–	X	X	–
Arthropoda	Crustacea	Decapoda	Cambaridae	<i>Faxonius punctimanus</i>	2.7	X	–	–	–	–	X	X
Arthropoda	Crustacea	Decapoda	Cambaridae	<i>Faxonius virilis</i>	2.7	–	–	–	–	–	–	–
Arthropoda	Crustacea	Isopoda	–	–	–	–	–	X	–	X	X	X
Arthropoda	Crustacea	Isopoda	Asellidae	<i>Caecidotea</i>	8	X	X	X	X	–	X	X
Arthropoda	Crustacea	Isopoda	Asellidae	<i>Lirceus hoppinae</i>	7.7	–	–	X	–	–	X	X
Arthropoda	Crustacea	Ostracoda	–	–	–	X	X	–	–	X	X	–
Arthropoda	Insecta	Coleoptera	Dytiscidae	–	–	–	–	–	–	–	X	–
Arthropoda	Insecta	Coleoptera	Dytiscidae	<i>Hydaticus</i>	5	–	–	–	–	–	X	–
Arthropoda	Insecta	Coleoptera	Elmidae	<i>Dubiraphia</i>	6.4	–	X	–	–	–	–	–
Arthropoda	Insecta	Coleoptera	Elmidae	<i>Optioservus sandersoni</i>	2.7	X	X	X	X	X	X	X
Arthropoda	Insecta	Coleoptera	Elmidae	<i>Stenelmis</i>	5.4	X	–	X	–	–	X	X
Arthropoda	Insecta	Coleoptera	Hydrophilidae	–	–	–	–	X	–	–	–	–
Arthropoda	Insecta	Coleoptera	Hydrophilidae	<i>Hydrobius</i>	5	X	–	–	–	–	–	–
Arthropoda	Insecta	Coleoptera	Scirtidae	<i>Prionocyphon</i>	ud	–	–	–	–	–	X	–
Arthropoda	Insecta	Collembola	–	–	–	X	X	X	X	X	X	X

Table A1 (continued). Aquatic invertebrates collected at springs located at Ozark National Scenic Riverways, 2007-2016. Environmentally sensitive taxa have tolerance values of 3 or less. X = present; ud = tolerance value for that species is undetermined.

Phylum	Class	Order	Family	Genus/species	Tolerance Value	Alley	Big	Blue	Phillips	Pulltite	Round	Welch
Arthropoda	Insecta	Diptera	Athericidae	<i>Atherix</i>	2.1	–	–	–	–	–	–	X
Arthropoda	Insecta	Diptera	Ceratopogonidae	–	6	–	–	–	–	–	–	–
Arthropoda	Insecta	Diptera	Certaopogonidae	<i>Atrichopogon</i>	6	–	–	–	–	X	X	–
Arthropoda	Insecta	Diptera	Ceratopogonidae	<i>Bezzia</i>	6	X	X	X	–	–	X	–
Arthropoda	Insecta	Diptera	Certaopogonidae	<i>Bezzia/Palpomyia</i>	6	X	X	–	–	X		–
Arthropoda	Insecta	Diptera	Chironomidae	–	6	X	X	X	X	X	X	X
Arthropoda	Insecta	Diptera	Dixidae	<i>Dixa</i>	2.8	X	–	–	–	X	–	–
Arthropoda	Insecta	Diptera	Empididae	<i>Chelifera</i>	6	X	X	X	–	–	–	–
Arthropoda	Insecta	Diptera	Empididae	<i>Clinocera</i>	6	X		X	–	X	X	–
Arthropoda	Insecta	Diptera	Empididae	<i>Hemerodromia</i>	6	X	X	X	X	X	X	X
Arthropoda	Insecta	Diptera	Empididae	<i>Neoplasta</i>	6	X	X	X	X	X	X	X
Arthropoda	Insecta	Diptera	Empididae	<i>Trichoclinocera</i>	6	X	–	–	–	–	X	–
Arthropoda	Insecta	Diptera	Ephydriidae	–	–	–	–	–	X	–	–	–
Arthropoda	Insecta	Diptera	Ephydriidae	<i>Scatella</i>	6	X	–	X	–	X	X	X
Arthropoda	Insecta	Diptera	Muscidae	<i>Limnophora</i>	7	X	–	X	–	X	–	X
Arthropoda	Insecta	Diptera	Psychodidae	<i>Psychoda</i>	9.9	–	X	–	–	–	–	–
Arthropoda	Insecta	Diptera	Simuliidae	–	–	–	–	–	X	–	–	–
Arthropoda	Insecta	Diptera	Simuliidae	<i>Prosimulium</i>	2.6	X	–	X	–	X	X	X
Arthropoda	Insecta	Diptera	Simuliidae	<i>Simulium</i>	4.4	X	–	X	–	X	X	–
Arthropoda	Insecta	Diptera	Tabanidae	<i>Tabanus</i>	9.7	–	X	–	–	–	–	–
Arthropoda	Insecta	Diptera	Tanyderidae	<i>Protoplasia fitchii</i>	3	–	–	–	–	–	X	–
Arthropoda	Insecta	Diptera	Tipulidae	–	–	X	X	X	X	X	–	–
Arthropoda	Insecta	Diptera	Tipulidae	<i>Antocha</i>	4.6	–	X	X	X	X	–	–
Arthropoda	Insecta	Diptera	Tipulidae	<i>Hexatoma</i>	4.7	X	–	–	X	–	–	–
Arthropoda	Insecta	Diptera	Tipulidae	<i>Pseudolimnophila</i>	7.3	X	–	–	–	–	–	–
Arthropoda	Insecta	Diptera	Tipulidae	<i>Tipula</i>	7.7	X	–	X	X	X	–	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	–	–	X	X	X	X	X	X	X

Table A1 (continued). Aquatic invertebrates collected at springs located at Ozark National Scenic Riverways, 2007-2016. Environmentally sensitive taxa have tolerance values of 3 or less. X = present; ud = tolerance value for that species is undetermined.

Phylum	Class	Order	Family	Genus/species	Tolerance Value	Alley	Big	Blue	Phillips	Pulltite	Round	Welch
Arthropoda	Insecta	Ephemeroptera	Baetidae	<i>Acentrella</i>	3.6	X	X	–	–	–	–	X
Arthropoda	Insecta	Ephemeroptera	Baetidae	<i>Baetis</i>	6	X	X	X	X	X	–	X
Arthropoda	Insecta	Ephemeroptera	Baetidae	<i>Pseudocloeon</i>	4.4	X	X	X	–	X	X	X
Arthropoda	Insecta	Ephemeroptera	Ephemerellidae	<i>Attenella</i>	1	X	–	–	–	X	–	X
Arthropoda	Insecta	Ephemeroptera	Ephemerellidae	<i>Ephemerella</i>	1.7	X	X	–	–	–	–	X
Arthropoda	Insecta	Ephemeroptera	Ephemerellidae	<i>Eurylophella</i>	3	X		–	–	X	X	X
Arthropoda	Insecta	Ephemeroptera	Ephemerellidae	<i>Serratella</i>	1.9	X	X	–	–	X	–	X
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	–	–	–	–	–	–	–	–	X
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	<i>Stenacron</i>	7.1	X	–	–	–	X	X	–
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	<i>Stenonema</i>	3.4	X	–	–	–	–	X	–
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	<i>Leptophlebia</i>	6.4	X	–	–	–	–	–	–
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	<i>Paraleptophlebia</i>	1.2	X	–	–	–	–	–	–
Arthropoda	Insecta	Ephemeroptera	Potamanthidae	<i>Anthopotamus</i>	1.6	–	X	–	–	–	X	–
Arthropoda	Insecta	Ephemeroptera	Tricorythidae	<i>Tricorythodes</i>	5.4	X	–	–	X	–	X	X
Arthropoda	Insecta	Hemiptera	Corixidae	–	–	–	X	–	–	–	X	–
Arthropoda	Insecta	Hemiptera	Corixidae	<i>Palmacorixa</i>	5.5	–	X	–	–	–	X	X
Arthropoda	Insecta	Hemiptera	Hebridae	<i>Lipogomphus</i>	ud	–	–	–	–	–	X	–
Arthropoda	Insecta	Hemiptera	Veliidae	<i>Microvelia</i>	6.4	X	–	X	–	X	X	–
Arthropoda	Insecta	Lepidoptera	Noctuidae	–	ud	–	X	–	–	–	–	–
Arthropoda	Insecta	Megaloptera	Corydalidae	<i>Corydalus cornutus</i>	5.6	X	–	–	–	–	–	–
Arthropoda	Insecta	Megaloptera	Corydalidae	<i>Nigronia serricornis</i>	5.5	X	–	X	X	X	X	X
Arthropoda	Insecta	Megaloptera	Sialidae	<i>Sialis joppa</i>	7.5	X	–	–	–	–	–	–
Arthropoda	Insecta	Neuroptera	Sisyridae	<i>Climacia areolaris</i>	6.5	–	–	X	–	–	–	–
Arthropoda	Insecta	Odonata	Aeshnidae	<i>Boyeria vinosa</i>	6.3	X	–	–	–	–	–	–
Arthropoda	Insecta	Odonata	Coenagrionidae	–	9	–	X	–	X	–	–	–
Arthropoda	Insecta	Odonata	Coenagrionidae	<i>Argia</i>	8.7	–	–	–	X	–	X	–
Arthropoda	Insecta	Odonata	Gomphidae	<i>Hagenius brevistylis</i>	4	–	–	–	–	–	–	–

Table A1 (continued). Aquatic invertebrates collected at springs located at Ozark National Scenic Riverways, 2007-2016. Environmentally sensitive taxa have tolerance values of 3 or less. X = present; ud = tolerance value for that species is undetermined.

Phylum	Class	Order	Family	Genus/species	Tolerance Value	Alley	Big	Blue	Phillips	Pulltite	Round	Welch
Arthropoda	Insecta	Plecoptera	Capniidae	<i>Allocaonia</i>	2.8	X	–	–	–	–	–	–
Arthropoda	Insecta	Plecoptera	Chloroperlidae	–	1	X	–	–	–	–	–	–
Arthropoda	Insecta	Plecoptera	Leuctridae	–	0	–	–	–	–	–	–	–
Arthropoda	Insecta	Plecoptera	Leuctridae	<i>Leuctra</i>	0.7	X	–	X	–	–	–	–
Arthropoda	Insecta	Plecoptera	Leuctridae	<i>Zealeuctra</i>	0	X	–	X	–	X	–	X
Arthropoda	Insecta	Plecoptera	Perlidae	–	1	X	–	–	X	X	–	–
Arthropoda	Insecta	Plecoptera	Perlidae	<i>Agnetina</i>	1.4	X	–	–	–	–	–	–
Arthropoda	Insecta	Plecoptera	Perlidae	<i>Neoperla</i>	1.6	X	–	–	–	–	–	–
Arthropoda	Insecta	Plecoptera	Perlodidae	<i>Cliperla clio</i>	4.8	X	–	–	–	–	–	–
Arthropoda	Insecta	Plecoptera	Perlodidae	<i>Isoperla</i>	2	X	–	–	–	–	–	–
Arthropoda	Insecta	Plecoptera	Taeniopterygidae	<i>Strophopteryx</i>	2.5	X	–	–	–	–	–	–
Arthropoda	Insecta	Plecoptera	Taeniopterygidae	<i>Taeniopteryx</i>	6.3	–	–	–	X	–	–	–
Arthropoda	Insecta	Trichoptera	Brachycentridae	<i>Brachycentrus</i>	2.2	–	X	–	–	–	–	–
Arthropoda	Insecta	Trichoptera	Glossosomatidae	<i>Glossosoma intermedium</i>	1.5	X	X	X	X	X	X	X
Arthropoda	Insecta	Trichoptera	Glossosomatidae	<i>Protoptila</i>	2.8	–	X	–	–	–	–	–
Arthropoda	Insecta	Trichoptera	Helicopsychidae	<i>Helicopsyche borealis</i>	0	X	–	–	X	X	X	X
Arthropoda	Insecta	Trichoptera	Hydropsychidae	<i>Ceratopsyche</i>	1.4	X	X	X	X	X	X	X
Arthropoda	Insecta	Trichoptera	Hydropsychidae	<i>Cheumatopsyche</i>	6.6	X	X	X	X	X	X	X
Arthropoda	Insecta	Trichoptera	Hydroptilidae	<i>Hydroptila</i>	6.2	X	X	X	X	X	X	X
Arthropoda	Insecta	Trichoptera	Hydroptilidae	<i>Oxyethira</i>	3	X	–	–	–	–	X	–
Arthropoda	Insecta	Trichoptera	Lepidostomatidae	<i>Lepidostoma togatum</i>	1	X	X	X	X	X	X	X
Arthropoda	Insecta	Trichoptera	Limnephilidae	<i>Pycnopsyche</i>	2.3	X	–	–	–	–	–	–
Arthropoda	Insecta	Trichoptera	Polycentropodidae	<i>Polycentropus</i>	3.5	–	X	–	–	–	–	–
Arthropoda	Insecta	Trichoptera	Psychomyiidae	<i>Lype diversa</i>	4.3	–	–	–	–	X	–	–
Arthropoda	Insecta	Trichoptera	Psychomyiidae	<i>Psychomyia flavida</i>	3.3	X	–	–	–	–	–	–
Arthropoda	Insecta	Trichoptera	Rhyacophilidae	<i>Rhyacophila</i>	0.8	X	–	–	–	X	–	–

Table A1 (continued). Aquatic invertebrates collected at springs located at Ozark National Scenic Riverways, 2007-2016. Environmentally sensitive taxa have tolerance values of 3 or less. X = present; ud = tolerance value for that species is undetermined.

Phylum	Class	Order	Family	Genus/species	Tolerance Value	Alley	Big	Blue	Phillips	Pulltite	Round	Welch
Mollusca	Bivalvia	Veneroidea	Sphaeriidae	<i>Pisidium</i>	6.8	X	X	–	–	X	X	X
Mollusca	Bivalvia	Veneroidea	Sphaeriidae	<i>Sphaerium/Musculium</i>	7.7	X	–	–	X	X	–	–
Mollusca	Gastropoda	Basommatophora	Lymnaeidae	<i>Pseudosuccinea</i>	7.2	X	–	–	–	–	–	–
Mollusca	Gastropoda	Basommatophora	Lymanaeidae	<i>Fossaria</i>	6	X	–	–	–	–	–	–
Mollusca	Gastropoda	Basommatophora	Physidae	<i>Physella</i>	9.1	X	X	X	X	X	X	X
Mollusca	Gastropoda	Limnophila	Ancylidae	<i>Ferrissia</i>	6.9	X	–	X	–	–	–	–
Mollusca	Gastropoda	Limnophila	Hydrobiidae	<i>Amnicola</i>	4.8	X	X	X	X	X	X	X
Mollusca	Gastropoda	Limnophila	Hydrobiidae	<i>Fontigens</i>	ud	X	–	–	–	–	–	–
Mollusca	Gastropoda	Limnophila	Pleuroceridae	<i>Elimia</i>	2.5	X	X	X	X	–	–	X
Nematoda	Nematoda	Nematoda	–	–	5	X	X	X	–	–	X	–
Nematomorpha	Nematomorpha	Nematomorpha	–	–	5	X	X	X	–	X	X	X
Platyhelminthes	Turbellaria	Tricladida	Planariidae	<i>Dugesia</i>	7.5	X	X	X	–	X	X	X
Platyhelminthes	Turbellaria	Tricladida	Planariidae	<i>Phagocata</i>	ud	X	X	X	X	X	X	X

Appendix B: Water Quality Data

Table B1. Water quality data for Alley Spring at Ozark National Scenic Riverways using water quality data loggers, 2007–2016.

Year	Statistic	Water Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)
2007	Mean	13.85	249.9	8.40	7.52	3.09
	Standard Error	0.006	4.93	0.07	0.002	0.011
	N	70	70	70	70	70
2008	Mean	13.64	293.68	9.63	7.43	0.60
	Standard Error	0.004	0.10	0.02	0.002	0.003
	N	31	31	31	31	31
2009	Mean	13.56	286.63	9.32	7.33	0.12
	Standard Error	0.003	0.16	0.02	0.002	0.006
	N	116	116	116	116	116
2010	Mean	13.82	312.71	9.38	7.40	0.09
	Standard Error	0.01	0.76	0.03	0.002	0.01
	N	24	24	24	24	24
2011	Mean	13.75	297.25	9.90	7.30	0.46
	Standard Error	0.004	0.09	0.01	0.001	0.007
	N	68	68	68	68	68
2012	Mean	14.07	256.02	11.33	7.40	1.20
	Standard Error	0.01	2.71	0.04	0	0.06
	N	48	48	48	48	48
2013	Mean	13.70	265.11	8.31	7.19	0.02
	Standard Error	0.003	1.29	0.01	0.00	0.01
	N	71	71	71	71	71
2014	Mean	13.87	233.63	8.67	7.17	0.07
	Standard Error	0	4.35	0.01	0	0.03
	N	19	19	19	19	19
2015	Mean	13.77	175.90	9.39	6.93	2.37
	Standard Error	0	0.56	0.04	0	0.03
	N	96	96	96	96	96
2016	Mean	13.81	222.86	11.85	6.83	3.34
	Standard Error	0	1.9	0.05	0	0.03
	N	92	92	92	92	92

Table B2. Water quality data for Big Spring at Ozark National Scenic Riverways using water quality data loggers, 2007–2016.

Year	Statistic	Water Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)
2007	Mean	14.37	349.74	10.35	7.53	2.64
	Standard Error	0.01	0.93	0.04	0.002	0.04
	N	77	77	77	77	77
2008	Mean	13.94	318.95	9.22	7.33	1.6
	Standard Error	0.01	1.29	0.02	0.01	0.07
	N	40	40	40	40	40
2009	Mean	14.30	342.65	8.58	7.36	0.42
	Standard Error	0.01	0.1	0.04	0.002	0.12
	N	26	26	26	26	26
2010	Mean	14.18	343.96	9.35	7.32	0.41
	Standard Error	0.01	1.42	0.04	0.005	0.16
	N	24	24	24	24	24
2011	Mean	14.18	309.61	12.05	7.33	1.91
	Standard Error	0.01	3.02	0.17	0.002	0.01
	N	70	70	70	70	70
2012	Mean	14.16	284.15	8.53	7.39	4.36
	Standard Error	0.01	0.82	0.04	0.00	0.09
	N	39	39	39	39	39
2013	Mean	14.4	342.70	8.38	8.06	n/a
	Standard Error	0	5.45	0.27	0.17	n/a
	N	3	3	3	3	3
2014	Mean	14.26	300.93	8.17	6.97	0.91
	Standard Error	0.01	0.3	0.02	0	0.01
	N	68	68	68	68	68
2015	Mean	14.17	284.32	8.33	6.94	0.69
	Standard Error	0.01	1.51	0.01	0	0.02
	N	22	22	22	22	22
2016	Mean	14.29	251.67	9.09	6.97	1.76
	Standard Error	0.01	2.78	0.03	0	0.06
	N	124	124	124	124	124

Table B3. Water quality data for Blue Spring at Ozark National Scenic Riverways using water quality data loggers, 2007–2016.

Year	Statistic	Water Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)
2007	Mean	13.71	127.93	8.89	7.60	5.07
	Standard Error	0.003	5.97	0.03	0.001	0.01
	N	42	42	42	42	42
2008	Mean	13.38	233.54	9.48	7.54	0.20
	Standard Error	0.005	4.99	0.06	0.002	0.03
	N	24	24	24	24	24
2009	Mean	13.75	227.85	10.05	7.43	0.08
	Standard Error	0.002	4.88	0.04	0.004	0.008
	N	48	48	48	48	48
2010	Mean	13.66	n/a	10.22	7.54	0.02
	Standard Error	0.003	n/a	0.06	0.001	0.01
	N	46	n/a	46	46	46
2011	Mean	13.74	272.67	9.76	7.49	0.16
	Standard Error	0.001	1.1	0.06	0.0005	0.005
	N	162	162	162	162	162
2012	Mean	13.45	208.47	8.79	7.53	0.40
	Standard Error	0.00	4.12	0.05	0	0
	N	53	53	53	53	53
2013	Mean	13.61	151.59	9.63	7.39	0.00
	Standard Error	0.00	6.39	0.03	0.00	0.00
	N	64	64	64	64	64
2014	Mean	13.72	201.96	7.10	7.06	0.30
	Standard Error	0	8.74	0.03	0.02	0
	N	25	25	25	25	25
2015	Mean	15.35	188.77	7.81	6.76	0.60
	Standard Error	0	1.8	0.01	0	0.01
	N	94	94	94	94	94
2016	Mean	15.33	144.91	7.87	6.91	2.47
	Standard Error	0	1.25	0.02	0	0.13
	N	166	166	166	166	166

Table B4. Water quality data for Pulltite Spring at Ozark National Scenic Riverways using water quality data loggers, 2007–2016.

Year	Statistic	Water Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)
2007	Mean	14.03	295.84	8.42	7.38	5.77
	Standard Error	0.001	0.14	0.005	0.001	0.01
	N	98	98	98	98	98
2008	Mean	13.76	277.96	8.22	7.36	0.89
	Standard Error	0.001	0.12	0.02	0	0.005
	N	48	48	48	48	48
2009	Mean	13.80	288.79	8.25	7.27	0.57
	Standard Error	0.0004	0.09	0.003	0.001	0.01
	N	47	47	47	47	47
2010	Mean	13.76	310.36	9.15	7.34	0.01
	Standard Error	0.001	0.1	0.01	0.003	0.01
	N	22	22	22	22	22
2011	Mean	13.62	284.52	8.46	7.25	2.05
	Standard Error	0.0004	0.12	0.01	0.0004	0.004
	N	150	150	150	150	150
2012	Mean	13.82	299.00	8.67	7.40	0.87
	Standard Error	0	0	0.01	0	0.01
	N	23	23	23	23	23
2013	Mean	13.42	231.98	9.48	7.29	10.93
	Standard Error	0.00	2.47	0.03	0.00	3.12
	N	362	362	362	362	362
2014	Mean	13.72	281.76	7.77	6.98	0.80
	Standard Error	0	0.1	0.01	0	0
	N	21	21	21	21	21
2015	Mean	14.23	233	7.46	6.83	1.03
	Standard Error	0.04	0	0.03	0.02	0.03
	N	4	4	4	4	4
2016	Mean	14.16	251.67	7.74	7.81	0.13
	Standard Error	0	0.33	0.06	0.11	0.09
	N	3	3	3	3	3

Table B5. Water quality data for Round Spring at Ozark National Scenic Riverways using water quality data loggers, 2007–2016.

Year	Statistic	Water Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)
2007	Mean	13.82	202.93	9.06	7.44	5.64
	Standard Error	0.02	2.17	0.04	0.002	0.01
	N	69	69	69	69	69
2008	Mean	13.60	311.04	9.27	7.40	1.18
	Standard Error	0.02	0.5	0.07	0.003	0.2
	N	25	25	25	25	25
2009	Mean	13.67	306.96	9.11	7.27	0.27
	Standard Error	0.006	0.98	0.02	0.001	0.02
	N	184	184	184	184	183
2010	Mean	13.67	353.45	9.71	7.44	0.28
	Standard Error	0.02	0.6	0.05	0.003	0.08
	N	31	31	31	31	31
2011	Mean	13.83	253.84	9.46	7.34	0.47
	Standard Error	0.01	1.76	0.04	0.001	0.01
	N	151	151	151	151	151
2012	Mean	14.02	231.67	8.83	7.43	1.17
	Standard Error	0.02	9.09	0.05	0.00	0.19
	N	39	39	39	39	39
2013	Mean	12.98	319.38	9.14	7.45	0.26
	Standard Error	0.01	0.24	0.03	0.00	0.02
	N	68	68	68	68	68
2014	Mean	13.86	185.73	8.42	7.17	0.45
	Standard Error	0.04	0.83	0.08	0.01	0.1
	N	22	22	22	22	22
2015	Mean	12.90	181.00	6.51	6.84	3.59
	Standard Error	0.01	1.57	0.05	0	0.03
	N	98	98	98	98	98
2016	Mean	13.9	236.55	8.22	7.75	3.68
	Standard Error	0.01	0.6	0.04	0.02	0.26
	N	20	20	20	20	20

Table B6. Water quality data for Welch Spring at Ozark National Scenic Riverways using water quality data loggers, 2007–2016.

Year	Statistic	Water Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)
2007	Mean	13.67	324.67	10.43	7.16	5.00
	Standard Error	0.006	3.33	0.18	0.03	0.1
	N	3	3	3	3	3
2008	Mean	13.51	314.00	n/a	7.37	0.2
	Standard Error	0.003	0	n/a	0.009	0.11
	N	3	3	3	3	3
2009	Mean	13.59	320.33	11.14	7.42	0.87
	Standard Error	0.05	0.33	0.21	0.04	0.43
	N	3	3	3	3	3
2010	Mean	13.57	337	9.68	7.24	0
	Standard Error	0.003	0	0	0.005	0
	N	3	3	3	3	3
2011	Mean	13.46	333	10.09	7.07	0.17
	Standard Error	0.01	0	0.27	0.01	0.12
	N	3	3	3	3	3
2012	Mean	13.80	355.87	8.45	7.39	n/a
	Standard Error	0	0.03	0.06	0.03	n/a
	N	3	3	3	3	3
2013	Mean	13.63	294.87	8.41	7.31	n/a
	Standard Error	0.03	0.09	0.20	0.08	n/a
	N	3	3	3	3	3
2014	Mean	13.49	304	8.68	6.81	0.43
	Standard Error	0	0	0.14	0.11	0.19
	N	3	3	3	3	3
2015	Mean	13.69	238	9.19	7.09	0.3
	Standard Error	0.01	0	1.14	0.06	0.3
	N	3	3	3	3	3
2016	Mean	13.68	285.00	8.57	7.86	.053
	Standard Error	0.01	0	0.10	0.06	0.39
	N	3	3	3	3	3

Table B7. Water quality data for Phillips Spring at Ozark National Scenic Riverways using water quality data loggers, 2007–2016.

Year	Statistic	Water Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)
2011	Mean	15.61	314.94	7.78	7.29	0.79
	Standard Error	0.001	2.08	0.041	0.001	0.005
	N	88	88	88	88	88
2012	Mean	15.35	312.44	8.34	7.35	0.60
	Standard Error	0	0.22	0.05	0	0
	N	18	18	18	18	18
2013	Mean	15.65	279.00	8.78	7.10	0
	Standard Error	0	0	0.03	0.04	0
	N	3	3	3	3	3
2014	Mean	14.50	286.87	6.87	7.19	0.06
	Standard Error	0	0.17	0.02	0	0.01
	N	62	62	62	62	62
2015	Mean	15.54	255.17	7.69	7.09	1.14
	Standard Error	0	0.17	0.01	0	0.02
	N	23	23	23	23	23
2016	Mean	15.52	259.84	6.07	8.08	0.06
	Standard Error	0	2.25	0	0.02	0.01
	N	101	101	101	101	101

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science

1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525