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Aquatic Macroinvertebrate and Physical Habitat Monitoring for Hermit Creek, Garden Creek, and Bright Angel Creek in Grand Canyon National Park

2012 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2014/683

ON THE COVER
Bright Angel Creek in Grand Canyon National Park
Photograph courtesy of SCPN

Aquatic Macroinvertebrate and Physical Habitat Monitoring for Hermit Creek, Garden Creek, and Bright Angel Creek in Grand Canyon National Park

2012 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2014/683

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1 Introduction and background

The National Park Service Inventory and Monitoring Program was designed to determine the current status and monitor long-term trends in the condition of park natural resources, providing park managers with a scientific foundation for making decisions and working with other agencies and the public to protect park ecosystems. Water-related vital signs are the fundamental components defining overall riparian and aquatic ecosystem integrity. The Southern Colorado Plateau Network (SCPN) has identified 7 vital signs pertaining to riparian and spring ecosystems, the first 2 of which we focus on in this report: 1) aquatic macroinvertebrates, 2) stream water quality, 3) stream flow and depth to groundwater, 4) spring water quality, 5) fluvial geomorphology, 6) riparian vegetation, composition, and structure, and 7) spring ecosystems. These vital signs are closely related and are all included in the *Vital Signs Monitoring Plan for the Southern Colorado Plateau Network* (Thomas et al. 2006). The context and ecological significance of these vital signs are further explained in Scott et al. (2005).

In 2009 SCPN implemented annual monitoring of aquatic macroinvertebrates and physical habitat on Hermit Creek in Grand Canyon National Park (GRCA) (Stumpf and Monroe 2011). During 2010 the SCPN water resources field crew added a site on Garden Creek and one on Bright Angel Creek (Stumpf and Monroe 2012a). Appendix A lists locations, codes, and common names of all sampling sites. Criteria used to select reach locations included the presence of riffle habitats, the feasibility of using sampling equipment throughout the reach, the absence of artificial structures, and the lack of tributary or spring inflows. During 2012, aquatic macroinvertebrate samples and physical habitat data were collected from all 3 monitoring sites.

Hermit Creek below Tonto Trail (GRCAHER01), identified in this report as HER01, is located just over 0.2 km downstream from the site of a USGS streamflow gage—*Hermit Creek above Tonto Trail nr Grand Canyon, AZ* (09403043)—maintained by GRCA staff (Figure 1). The channel substrate at this site is primarily cobble and bedrock. The stream flows through a sparse willow (*Salix* sp.) shrubland with a dense monkey flower (*Mimulus* sp.) understory. The Hermit Fault acts as one of the main pathways for the flow of groundwater from the south rim. Consequently, Hermit Creek is one of the larger streams in this section of the Grand Canyon. At the streamflow gaging station (*Hermit Creek above Tonto Trail nr Grand Canyon),* which was established on Hermit Creek in 1994, GRCA has collected both streamflow data and periodically collected water quality samples. Unfortunately, the *Hermit Creek above Tonto Trail nr Grand Canyon* gaging station was destroyed during a flash flood event in September 2011. Aquatic macroinvertebrate data have been collected sporadically at Hermit Creek by the state of Arizona from 1992–2009 (Lawson 2007). SCPN's monitoring site is just downstream of the popular Hermit Creek campground and one of the criteria for selecting this site was to assess potential impacts on Hermit Creek resulting from human activities associated with the campground.

Garden Creek below Tonto Trail (GRCAGAR01), identified in this report as GAR01, is located approximately 9.3 km downstream from the Bright Angel Trailhead (Figure 2). The channel substrate is primarily fines and coarse gravels and flows through a dense willow (*Salix* sp.) shrubland with a sparse horsetail (*Equisetum* sp.) understory. Garden Creek flows parallel to the Bright Angel Trail, one of the most popular and traveled of trails in GRCA. The lower end of the creek crosses the trail multiple times before converging with Pipe Creek, which eventually flows into the Colorado River. This trail is frequented by the hiking public as well as concessionaires who provide transportation through the inner canyon via mule. Up to 10 mule trips a day can occur along the Bright Angel Trail. The effects of mules on water quality in Garden Creek are poorly understood. Indian Gardens, a popular resting site for backcountry travelers on foot and by mule, is located adjacent to the stream, approximately 1 km upstream from our sampling site. Additionally, a large campground is located at Indian Gardens. Grand Canyon staff are concerned with the impact of high level visitation on Garden Creek. One specific reason for selecting this site was to assess impacts downstream of the campground and the livestock corral. Another factor potentially influencing this site is external water input. The park pumps water from Roaring Springs on the North Rim up to Indian Gardens and the South Rim via the Transcanyon pipeline. At various time of the day, when pumping is not active, this water is returned to Garden Creek at Indian Gardens. It is unclear what the effect of this water is on the aquatic and riparian ecosystems of Garden Creek.

Bright Angel Creek below first footbridge (GRCABRI01), identified in this report as BRI01, is located upstream from Phantom Ranch, and downstream from the first large steel footbridge on the North Kaibab Trail (Figure 2). The site was located above Phantom Ranch to avoid ranch impacts on streamflow. Bright Angel Creek flows from the North Rim of GRCA and runs parallel to the North Kaibab Trail before eventually draining into the Colorado River below Phantom Ranch. The channel substrate at this site is primarily cobbles and flows through a willow (*Salix* sp.) shrubland with a horsetail (*Equisetum* sp.) understory. USGS gaging station, *Bright Angel Creek near Grand Canyon, AZ* 09403000, monitors streamflow near the confluence of Bright Angel Creek and the Colorado River. During the fall and winter months of 2002–2003, the park began a trout reduction project in Bright Angel Creek. The goal of the project was to reduce the number of nonnative brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) from the creek. This project continued during the fall and winter months of 2006–2007, 2010–2011, and 2011–2012. It is unclear how the removal efforts will affect aquatic macroinvertebrate taxa.

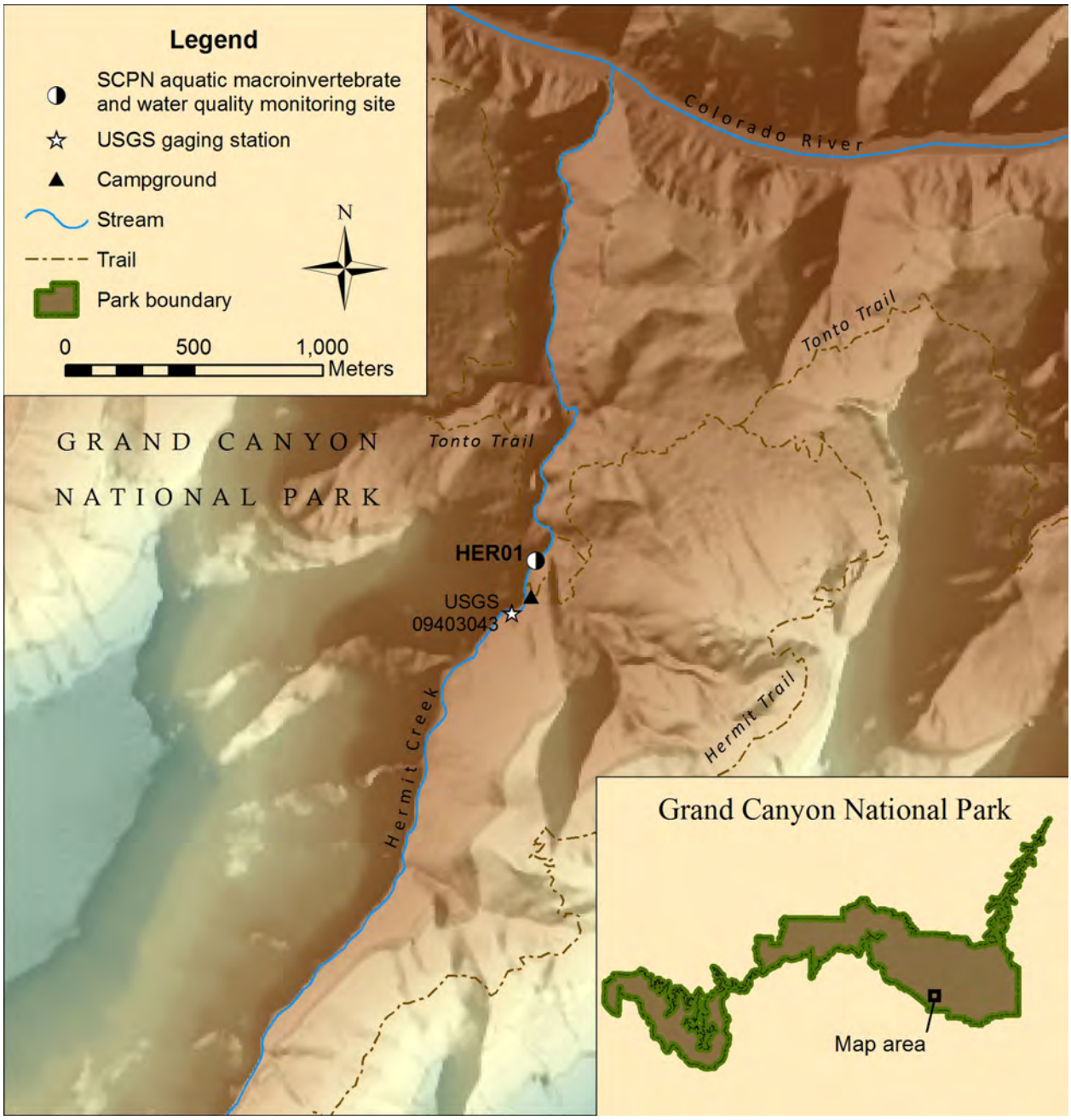


Figure 1. Map of the HER01 (Hermit Creek) monitoring site in Grand Canyon National Park, Arizona, 2012. The USGS gaging station was destroyed by flooding in 2011, but the site is still included on this map for reference.

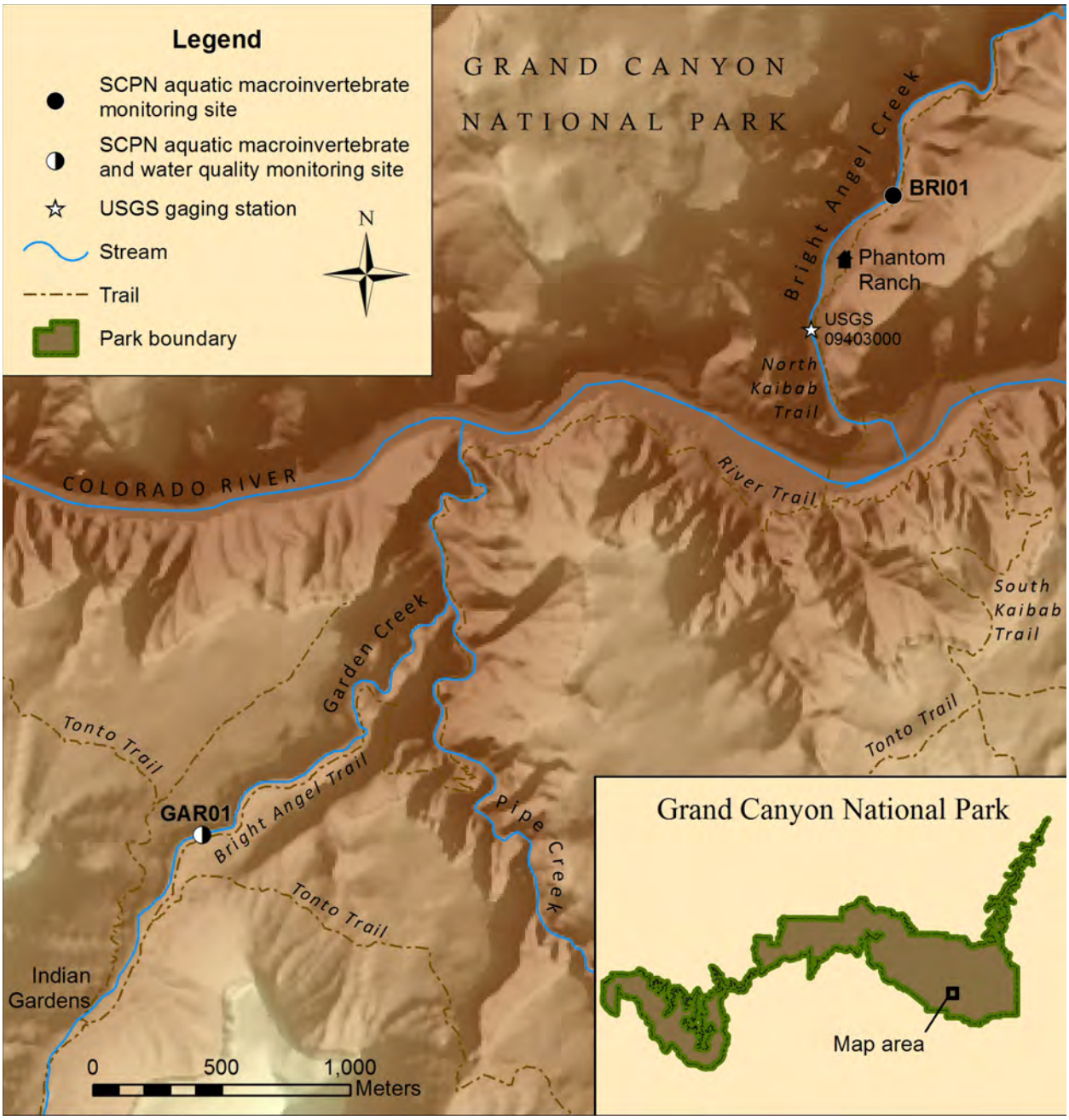


Figure 2. Map of the BRI01 (Bright Angel Creek) and the GAR01 (Garden Creek) monitoring sites in Grand Canyon National Park, Arizona, 2012.

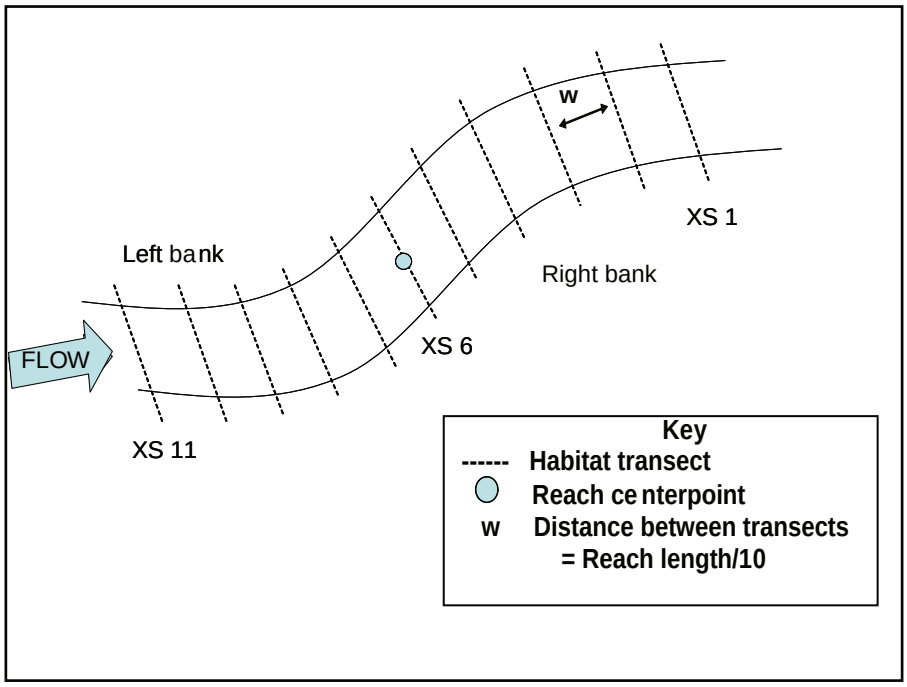
The purpose of this report is to (a) document SCPN aquatic macroinvertebrate monitoring activities that occurred at Hermit Creek, Garden Creek, and Bright Angel Creek in GRCA in 2012, (b) summarize the data collected, and (c) where appropriate, place the data in the context of current environmental conditions.

2 Methods

2.1 Field methods

In Arizona, the aquatic macroinvertebrate sampling window for streams <1,500 m elevation is from April to May (Arizona Department of Environmental Quality, Water Quality Division 2006). On 18 April 2012, we collected aquatic macroinvertebrate samples and physical habitat data at the monitoring site, HER01. We collected aquatic macroinvertebrate and physical habitat samples from GAR01 on 25 April 2012 and from BRI01 on 11 October 2012. BRI01 is a North Rim drainage which experiences annual spring stream flows above base flow due to snowmelt. Because of this we are unable to sample during the recommended sampling window. Instead SCPN has decided to implement a fall sampling strategy at BRI01 only. Each of these sites consists of a 150-meter reach, composed of 11 transects, spaced 15 m apart (Figure 3). A brief description of field methods is provided here, and a detailed description of sampling methods can be found in Brasher et al. (2011).

Figure 3. General aquatic macroinvertebrate sampling reach layout.



We collected 2 types of aquatic macroinvertebrate samples from each site:

- Replicate quantitative samples were collected from 5 targeted riffle habitats to provide estimates of abundances of organisms. We used a Slack sampler to collect a timed sample from a 0.25 m^2 area at each targeted riffle.
- A qualitative sample was collected to develop a comprehensive list of species present in the site. We used a Slack sampler to collect samples from all habitat types within the monitoring site and compiled them into one composite sample.

We collected physical habitat data at 3 spatial scales—microhabitat, transect, and reach:

- For each of the targeted riffle micro habitats where quantitative samples are collected we
  - measured depth
  - measured velocity
  - measured substrate particle size
  - measured substrate particle embeddedness

- For each of the 11 transects, we
  - measured wetted and active channel widths
  - estimated canopy closure at both ends and at the center of each transect
  - measured water depth and velocity at 5 equally spaced points along each transect
  - observed and recorded the presence or absence, and types of aquatic macroinvertebrate habitats, represented by point data (5 points/transect) across the entire site
  - identified and recorded geomorphic channel units (GCU) at 5 equally spaced points along each transect
- For the entire reach, we
  - identified and measured the length of GCUs (the proportion of the reach representing each GCU)
  - identified the dominant vegetation and land cover
  - recorded descriptions of flow conditions
  - recorded weather conditions
  - observed and recorded evidence of anthropogenic or natural disturbances
  - measured NPS core water quality parameters of temperature, specific conductivity, pH, dissolved oxygen, turbidity, and stream discharge
  - conducted a zig-zag pebble count measuring the size of a minimum of 400 randomly-selected particles using a modified Wolman pebble count across the length of the entire site

2.2 Hydrologic data collection

Hydrologic data presented in this report were collected at a weather station at Hopi Point, and at a USGS streamflow gaging station on Bright Angel Creek in GRCA.

For hydrologic conditions applicable to Hermit Creek and Garden Creek, daily precipitation measurements were collected at the National Atmospheric Deposition Program (NADP) station at Hopi Point (AZ03) (National Atmospheric Deposition Program 2013). For Bright Angel Creek, we report discharge, as well as air and water temperature data collected by USGS streamflow gaging station #09403000 (U.S. Geological Survey 2013).

2.3 Laboratory methods

Aquatic macroinvertebrate samples were sent to the National Aquatic Monitoring Center's Bug Lab, a Bureau of Land Management laboratory at Utah State University in Logan, Utah. There, samples were sorted under a dissecting scope at 10X magnification, and a 500-organism, fixed-count method was used for sub-sampling large samples. Ten percent of the sorted samples were re-sorted for quality assurance.

A taxonomist certified by the North American Benthological Society identified all aquatic macroinvertebrates to the family or genus level. To ensure data quality, 10 percent of the identified samples were re-identified by a second certified taxonomist.

Quantitative and qualitative aquatic macroinvertebrate samples will be maintained by the contract aquatic laboratory for at least 5 years to allow for repeat subsampling should any data questions arise. For a more detailed description of laboratory methods, see Brasher et al. (2011).

2.4 Data analysis

In this report we summarize aquatic macroinvertebrate data in terms of community structure and function. Genera were classified into functional feeding guilds using the classifications presented in Barbour et al. (1999). If functional class information was not available for a particular genus, we applied a more generalized, family-level classification.

For quantitative aquatic macroinvertebrate data, we calculate means and standard deviations from the 5 replicate samples collected. For those parameters measured along transects (such as habitat characterization), we calculate means and standard deviations from the 7 to 11 transect values.

We selected aquatic macroinvertebrate metrics that are generally considered to be sensitive, reliable indicators of water quality and/or stream health (see Appendix B for a table of metrics and their definitions). Most of these metrics have been used to detect changes in water quality and habitat conditions in other streams in the Southern Rocky Mountains ecoregion (Griffith et al. 2005). They also enable a comprehensive assessment of multiple aspects of community structure because they represent a range of ecological characteristics. SCPN will periodically evaluate the interpretive value of the listed metrics and may drop or add additional metrics based upon these evaluations.

3 Results

3.1 Aquatic macroinvertebrate community data for Hermit Creek

We present key metrics calculated from aquatic macroinvertebrate community data collected at HER01 from 2009 to 2012. Figures in this section refer to quantitative data unless otherwise noted, and error bars represent one standard deviation from the mean. All corresponding data values are available in table format in Appendix C (Tables C1, C2). Appendix D lists all aquatic macroinvertebrate species detected at the site, from both quantitative and qualitative methods.

Abundance. Abundance of aquatic macroinvertebrates at the quantitative targeted riffle habitat averaged 768.40 individuals per riffle (Figure 4), and ranged from a high of 889 individuals to a low of 630 individuals in 2012.

Taxa richness. Total richness of quantitative targeted riffle habitat averaged 13.80 taxa in 2012 (Figure 5). Richness ranged from a high of 16 taxa to a low of 11 taxa. Taxa richness for the qualitative sample was 11 taxa.

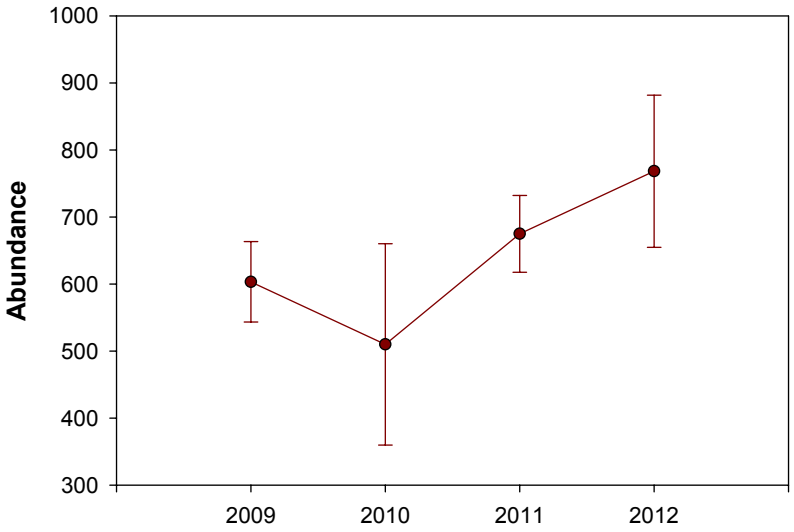


Figure 4. Aquatic macroinvertebrate abundance in samples from HER01 at Hermit Creek in GRCA, 2009–2012.

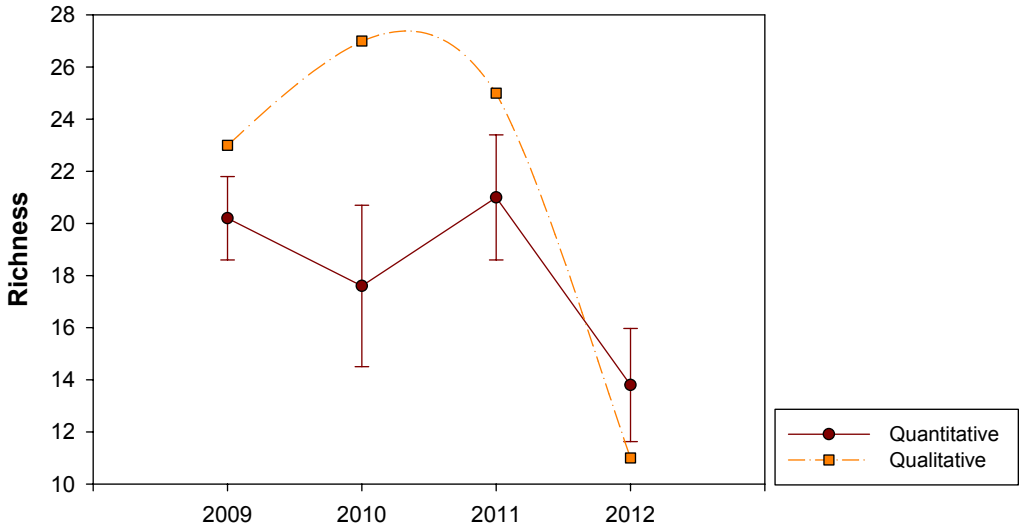


Figure 5. Taxa richness in quantitative and qualitative samples from HER01 at Hermit Creek in GRCA, 2009–2012.

Diversity. We calculated taxonomic and functional diversity using the Simpson's Diversity Index (Figure 6). Taxonomic diversity, averaging 0.41 per riffle, was over 3 times as high as functional diversity, which averaged 0.12 per sample in 2012.

Stress tolerance. Taxa which are moderately tolerant of disturbance dominated the relative abundance of aquatic macroinvertebrates, averaging 80.64% of the individuals collected in 2012 (Figure 7). Relative abundance of intolerant individuals averaged 18.55%, and tolerant individuals were the least abundant group, averaging 0.81%.

EPT taxa. Relative abundance of EPT taxa (Ephemeroptera [mayflies], Plecoptera [stoneflies], and Trichoptera [caddisflies]) at this monitoring site averaged 89.70% of all taxa collected in 2012 (Figure 8). Ephemeroptera was the overwhelmingly dominant EPT order, averaging 89.07% of individuals. Trichoptera averaged 0.63% of individuals collected. In 2012, as with the previous 3 years, there were no Plecoptera taxa found at HER01.

Aquatic macroinvertebrate orders. Of the aquatic macroinvertebrate orders collected from HER01, Ephemeroptera had the most individuals in 2012 (Figure 9). Non-Chironomidae Diptera (flies) were the next most abundant aquatic macroinvertebrates, at 5.16%. Chiromomidae (midges) averaged 3.45% of the samples, followed by Coleoptera at 1.26%. Trichoptera, Odonata (damselflies/dragonflies), and noninsect taxa (water mites) all averaged less than 1% at 0.63%, 0.10%, and 0.33%, respectively.

Functional feeding groups. The majority of the organisms collected from HER01 in 2012 belonged to the collector-gatherers functional group (93.46%) (Figure 10). Collector-filterers and predators were the next most abundant, at 4.85% and 1.62%, respectively. Shredders were the least abundant, at 0.08%, and scrapers were not detected in the quantitative samples in 2012.

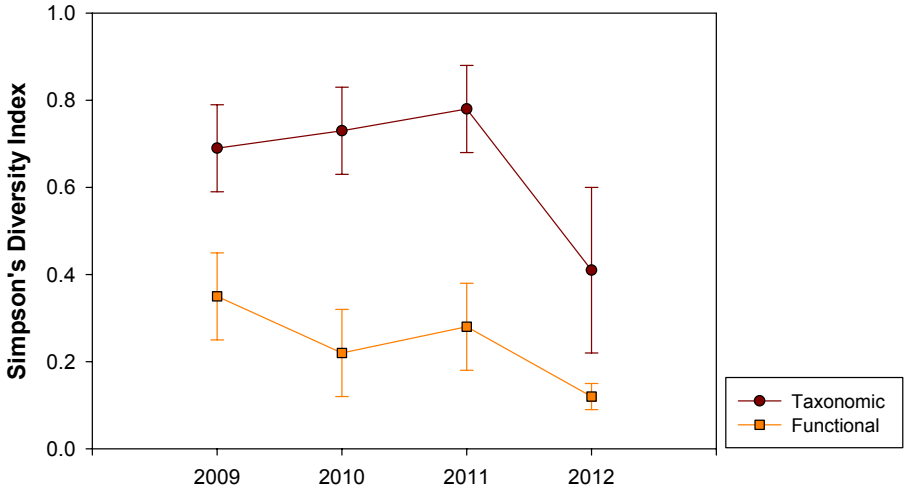


Figure 6. Taxonomic and functional diversity in samples from HER01 at Hermit Creek in GRCA 2009–2012.

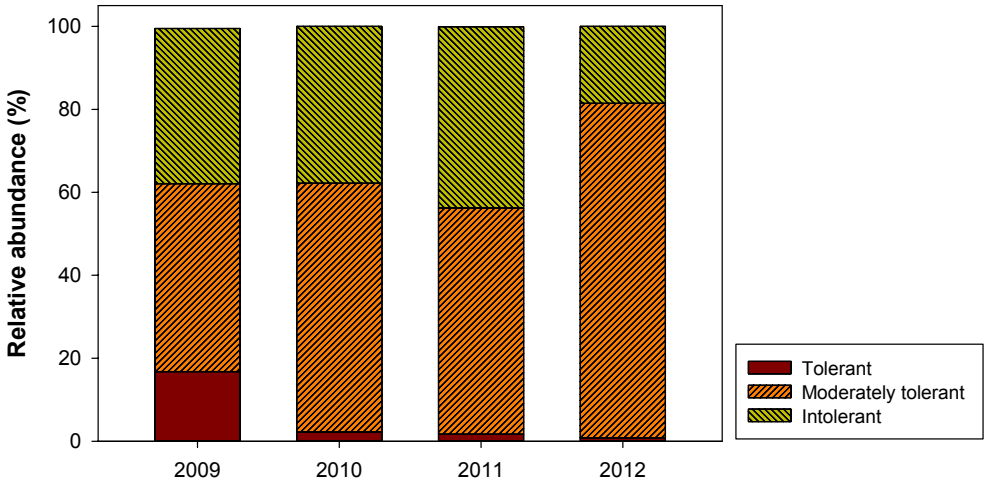


Figure 7. Mean relative abundance by tolerance group in aquatic macroinvertebrate samples from HER01 at Hermit Creek in GRCA, 2009–2012.

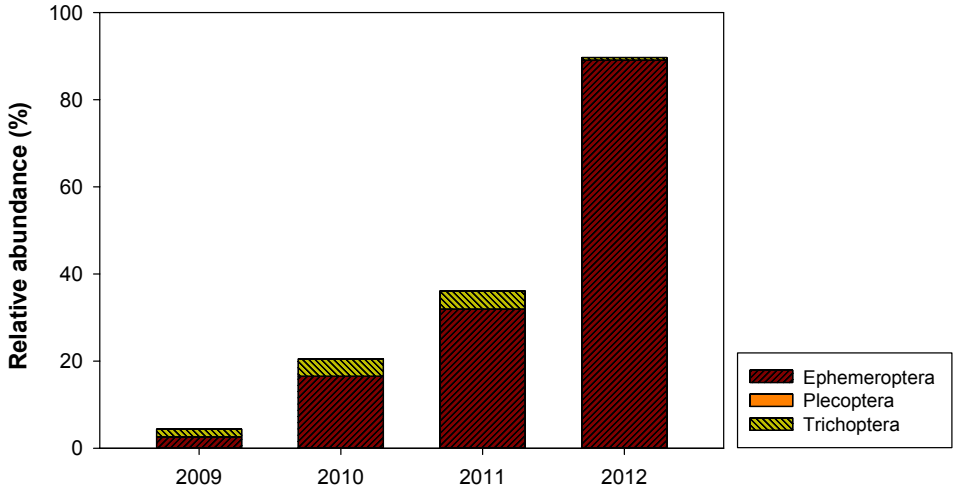


Figure 8. Mean relative abundance of aquatic macroinvertebrates belonging to sensitive EPT orders in samples from HER01 at Hermit Creek in GRCA, 2009–2012. No Plecoptera were found in these 4 years.

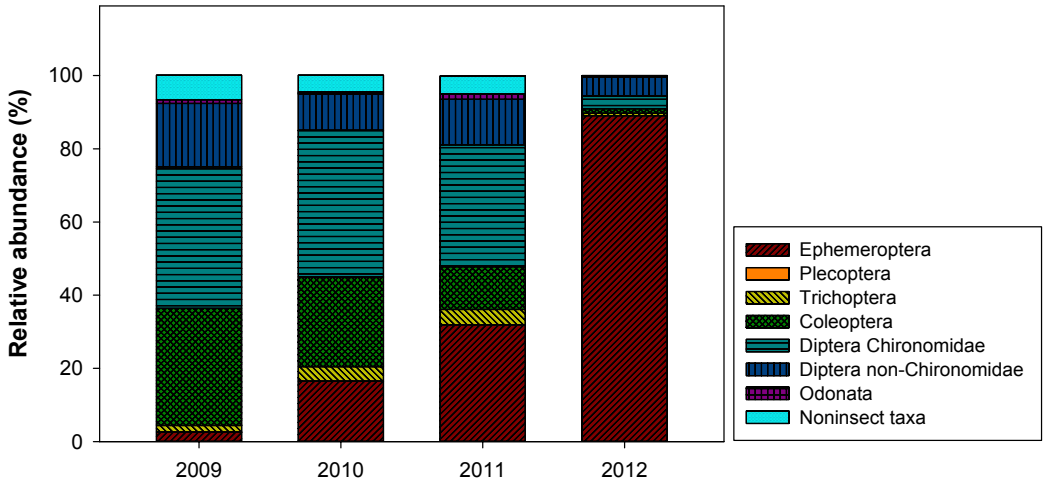


Figure 9. Mean relative abundance by taxonomic order in samples from HER01 at Hermit Creek in GRCA, 2009–2012.

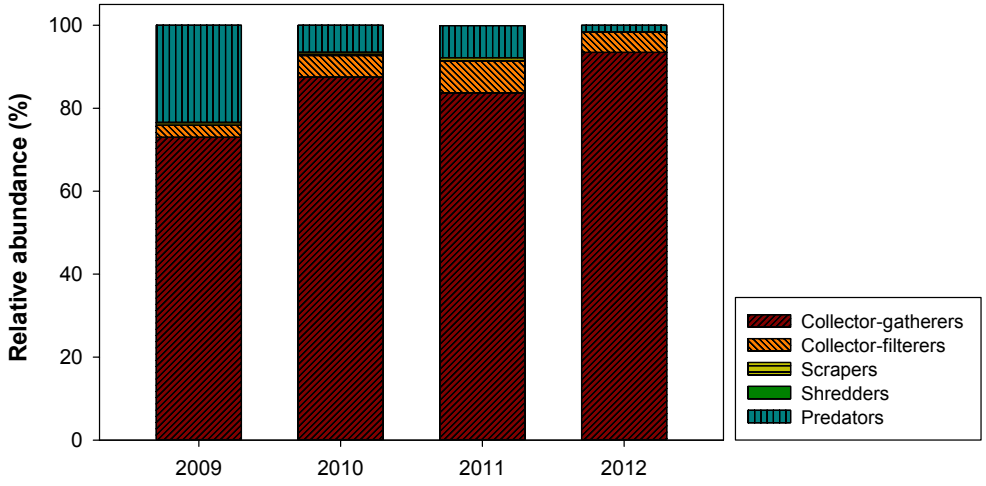


Figure 10. Mean relative abundance by functional feeding group in aquatic macroinvertebrate samples from HER01 at Hermit Creek in GRCA, 2009–2012. Some groups were not observed.

3.2 Physical habitat characteristics for Hermit Creek

We present data describing physical habitat characteristics collected at HER01 from 2009 to 2012 in this section. These data are summarized in table format in Appendix C (Table C3); additional transect data can be found in Appendix E.

Microhabitat level. Stream flow velocities at quantitative targeted riffle sites averaged 0.59 m/s in 2012. Average depth was 0.07 m, and an average of 18.0% of each particle was embedded in finer substrates.

Transect level. The average width of the active channel and wetted channel at the 11 physical habitat transects at HER01 in 2012 was 10.4 m and 3.4 m, respectively. Average velocity of stream flow was 0.17 m/s. Depths at transects along HER01 averaged 0.05 m. There was no riparian cover found along this reach in 2012.

Rock was the only aquatic macroinvertebrate habitat type found along transects in our monitoring site in 2012, found along 40.5% of the sampling reach (Figure 11). Substrate fitting the category "Absence", meaning it lacked habitat that we define as appropriate for aquatic macroinvertebrates, occurred along 59.5% of the site.

Reach level. Channel structure dynamics are represented by particle size distributions in Figure 12, based on modified Wolman pebble counts. In 2012, the dominant particle size class along HER01 was gravel (3–64 mm), representing 51.3% of particles sampled at the site. Cobbles (65–250 mm) and bedrock (>4000 mm) were the next most abundant, at 18.3% and 8.3% of the particles sampled, respectively. Particles that were too cemented to pull from the streambed for measurement comprised 8.3% of the samples. Sand (>0.06–2) and silt (<0.06 mm) made up 6.3% and 4.8% of the sample, respectively. Boulders (251–4000 mm) were the least abundant particles, representing 3.0% of the sample.

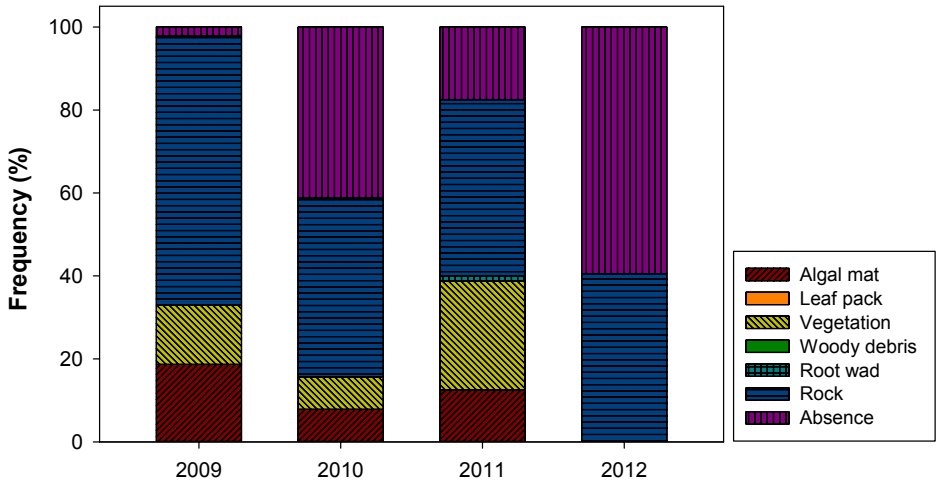


Figure 11. Habitat characterization expressed as frequency of occurrence along transects from HER01 at Hermit Creek in GRCA, 2009–2012. Some habitat structure types were not observed.

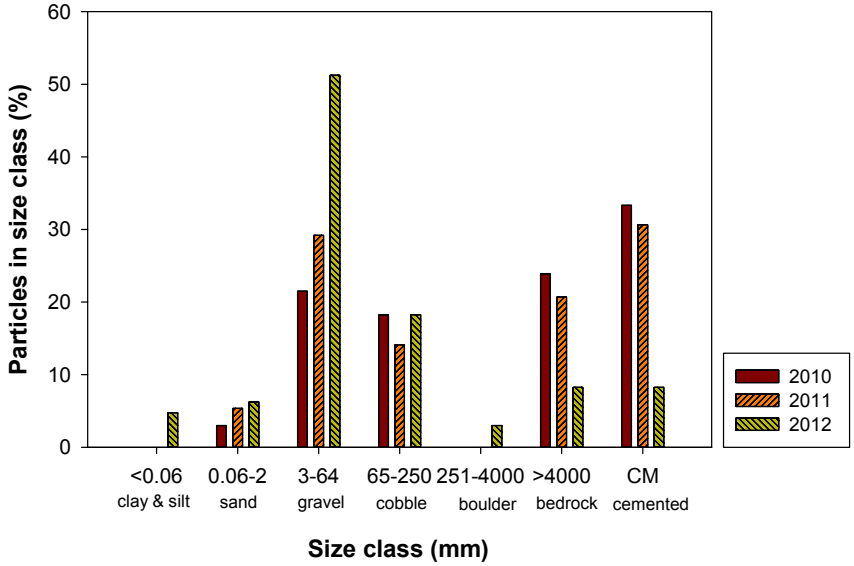


Figure 12. Particle size distribution from HER01 at Hermit Creek in GRCA, 2010–2012. Particles that are completely cemented into the stream channel preclude size measurements.

Runs were the dominant geomorphic channel unit (GCU) along the reach at our monitoring site in 2012, found along 45.9% of the site (Figure 13). Cascades were the next most abundant GCU, at 37.9%. Riffles made up 12.0% of the site. Scour pools were the least abundant, at 4.2%.

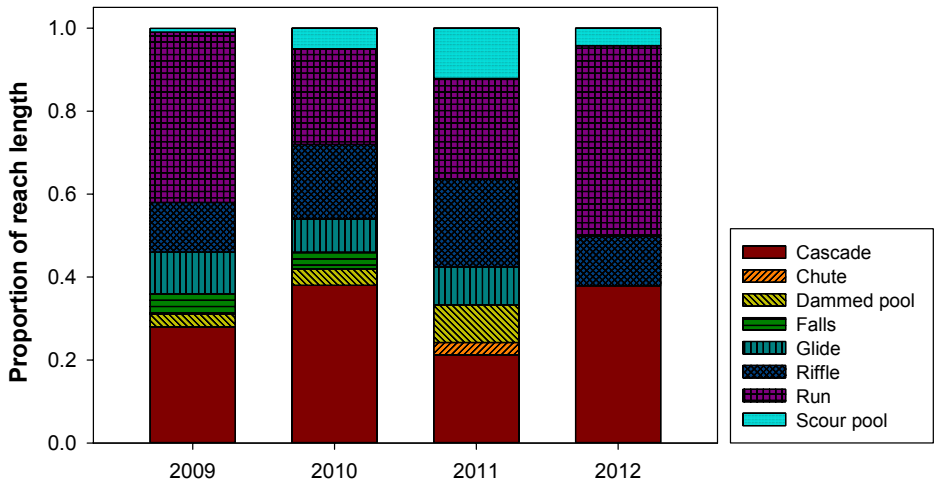


Figure 13. Geomorphic channel unit characterization of HER01 at Hermit Creek in GRCA, 2009–2012.

3.3 Hydrologic conditions for Hermit Creek

3.3.1 SCPN water quality core parameter data

We report NPS core water quality measurements collected at or near midday of the sample date for Hermit Creek in 2012. Data from all years of sampling at Hermit Creek (2009–2012) are available in table format in Appendix C (Table C3).

In 2012, the noon time water temperature at HER01 on our sampling day was 16.7°C. Specific conductivity and pH measured 442 µS/cm and 8.4 units, respectively. Dissolved oxygen measured 99.9% saturation and 8.7 mg/L. Stream discharge at the time of our visit was 0.6 cfs. Turbidity was 5.8 NTU.

We were not able to collect air or water temperature data because of the flood event that occurred on 11 September 2011, which destroyed the *Hermit Creek above Tonto Trail* gaging station and data loggers.

3.3.2 NADP precipitation data

Daily precipitation from the NADP/NTN AZ03 monitoring station at Hopi Point is shown in Figure 14. Moisture events were abundant and evenly spread across the entire year for 2012 (Figure 14). The driest portion of the year was during the early summer months of late May to mid-July.

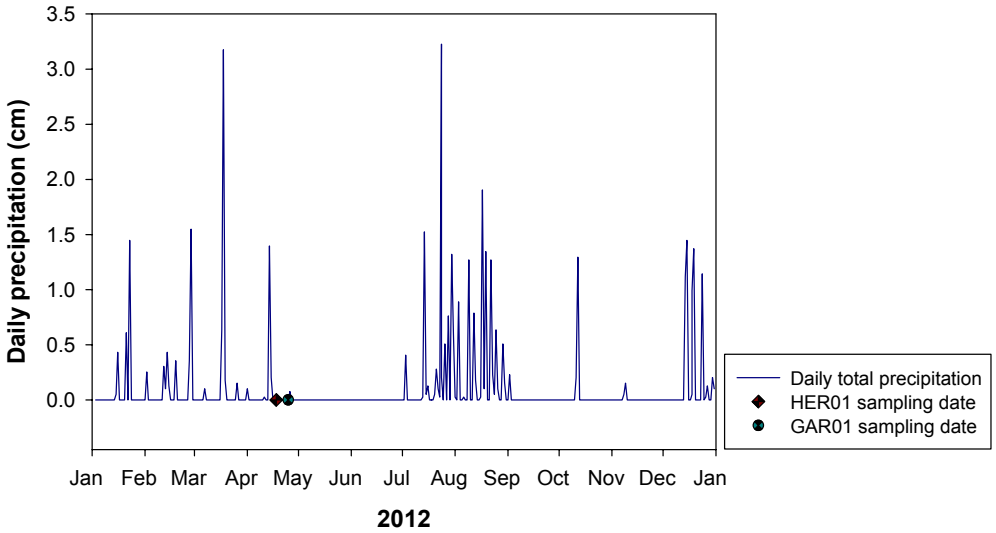


Figure 14. Total daily precipitation from the NADP/NTN AZ03 monitoring station at Hopi Point in GRCA. Precipitation data from this station are also applicable to the Garden Creek site (GAR01).

3.4 Aquatic macroinvertebrate community data for Garden Creek

We present key metrics calculated from sampling aquatic macroinvertebrate communities from 2010 to 2012 at GAR01. Figures in this section refer to quantitative data unless otherwise noted, and error bars in figures represent one standard deviation from the mean. All corresponding data values are available in table format in Appendix F (Tables F1, F2). Appendix D lists all aquatic macroinvertebrate species detected at the site, from both quantitative and qualitative methods.

Abundance. Mean total abundance for quantitative targeted riffle samples averaged 727.40 individuals in 2012 (Figure 15). Riffle sample abundances ranged from a low of 650 individuals to a high of 782 individuals.

Taxa richness. Total richness from quantitative riffle samples averaged 18.20 taxa per riffle in 2012 (Figure 16). Riffle richness ranged from a low of 16 taxa to a high of 22 taxa. Richness from the qualitative sample was 27 taxa.

Diversity. Taxonomic and functional diversity were measured using the Simpson's Diversity Index (Figure 17). In 2012, taxonomic diversity averaged 0.77, while functional diversity averaged 0.47.

Stress tolerance. Taxa which are moderately tolerant to disturbance dominated the relative abundance of aquatic macroinvertebrates in 2012, averaging 87.38% (Figure 18). Intolerant individuals averaged 12.02% of the samples, and tolerant individuals represented only 0.60% of the samples.

Figure 15. Aquatic macroinvertebrate abundance from GAR01 at Garden Creek in GRCA, 2010–2012.

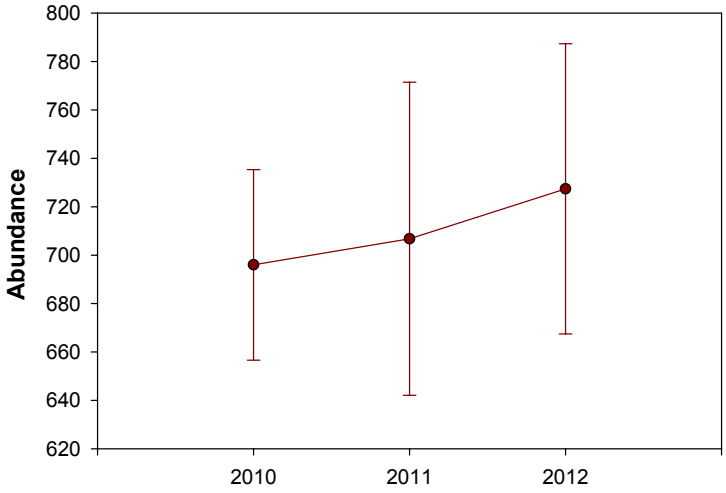
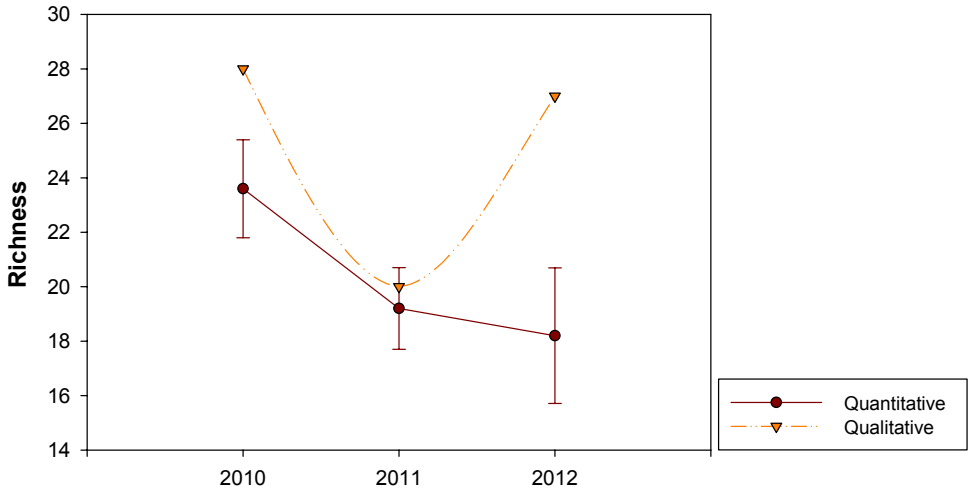


Figure 16. Taxa richness in quantitative and qualitative samples from GAR01 at Garden Creek in GRCA, 2010–2012.



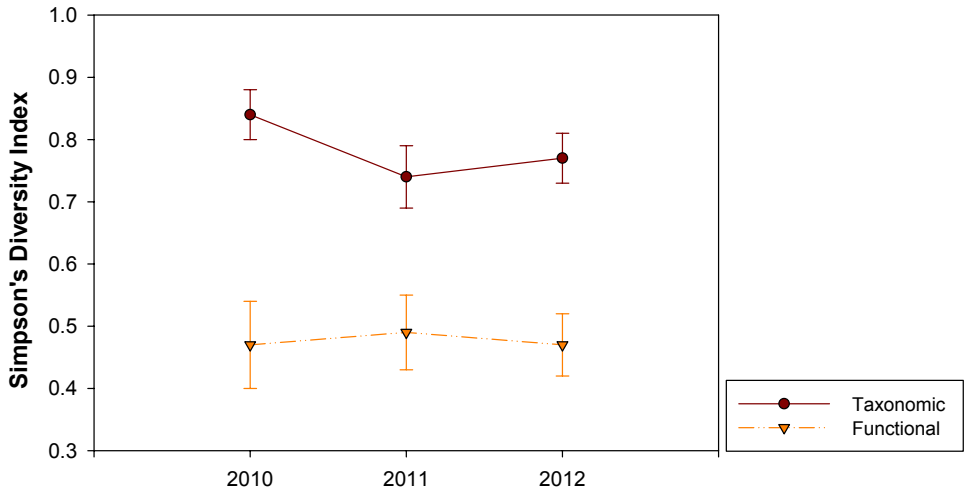


Figure 17. Taxonomic and functional diversity in samples from GAR01 at Garden Creek in GRCA, 2010–2012.

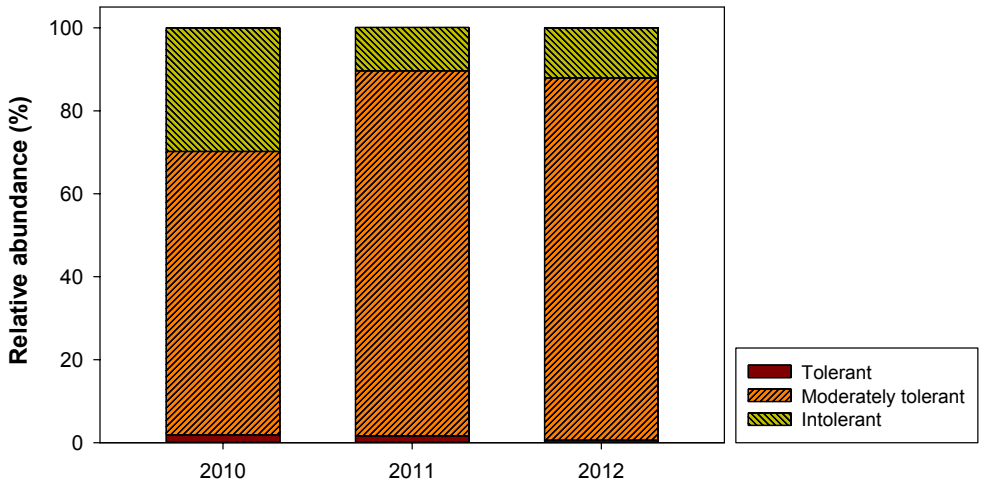


Figure 18. Mean relative abundance by tolerance group of aquatic macroinvertebrate samples from GAR01 at Garden Creek in GRCA, 2010–2012.

EPT taxa. Relative abundance of individuals in EPT taxa (Ephemeroptera, Plecoptera, and Trichoptera) at GAR01 in 2012 was highest for the order Ephemeroptera, which averaged 23.96% of the sample (Figure 19). Trichoptera accounted for 5.19% of the individuals collected. No Plecoptera were collected at this sampling site in 2012, or in the 2 previous years. Abundance of all 3 EPT taxa combined accounted for 29.14% of the total individuals collected at GAR01.

Aquatic macroinvertebrate orders. Chironomidae (33.52%) were the most abundant taxa among all the different orders collected at GAR01 in 2012 (Figure 20). Non-Chironomidae Diptera was the second most abundant order, at 28.08%. Coleoptera and Odonata were low in abundance, at 5.91% and 1.63%, respectively For GAR01, "Noninsect" taxa included Trombidiformes, Isopoda, as well as the phyla Annelida (segmented worms) and Platyhelminthes (flat worms), which together accounted for 1.71% of all individuals collected.

Functional feeding groups. Collector-gatherers were the most abundant of the functional groups collected from GAR01 in 2012, averaging 64.77% of the individuals collected (Figure 21). Collector-filterers were the second most abundant, at 31.81%. Predators accounted for 2.97% of the samples, and shredders were at 0.30%. Scrapers were the least abundant group, at 0.14%.

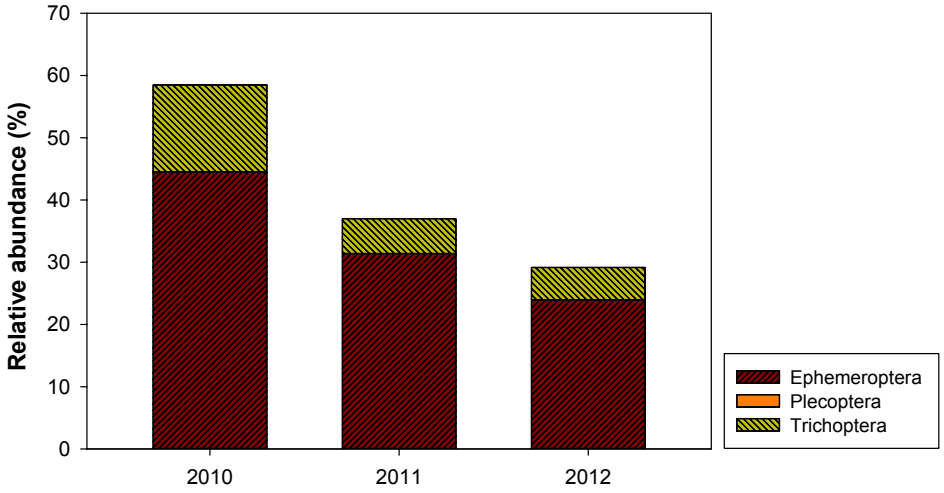


Figure 19. Mean relative abundance of aquatic macroinvertebrates belonging to sensitive EPT orders in samples from GAR01 at Garden Creek in GRCA, 2010–2012. During all 3 years, no plecopterans were found in these samples.

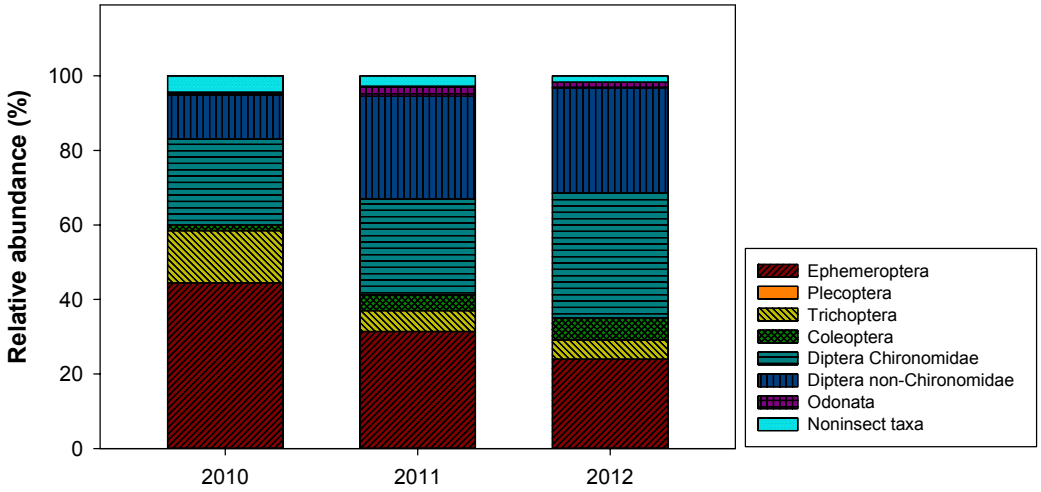


Figure 20. Mean relative abundance by taxonomic order in samples from GAR01 at Garden Creek in GRCA, 2010–2012. During all 3 years, no plecopterans were found in these samples.

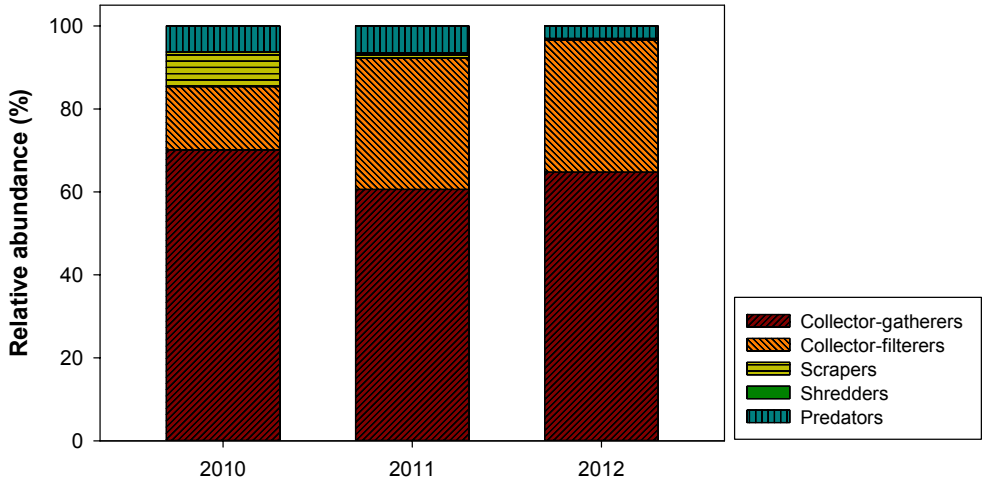


Figure 21. Mean relative abundance by functional feeding group in aquatic macroinvertebrate samples from GAR01 at Garden Creek in GRCA, 2010–2012. During all 3 years, shredders were <1%.

3.5 Physical habitat characteristics for Garden Creek

We present data describing physical habitat characteristics collected at GAR01 from 2010 to 2012 in this section. These data are summarized in table format in Appendix F (Table F3); additional transect data can be found in Appendix E.

Microhabitat level. Stream flow velocity at the quantitative targeted riffle sites averaged 0.84 m/s and depths averaged 0.10 m in 2012. Embeddedness of particles in the quantitative sampling frame averaged 20.8%.

Transect level. Active channel widths and wetted channel widths at the 11 physical habitat transects in 2012 averaged 10.8 m and 1.4 m, respectively. Stream flow velocity at the monitoring site averaged 0.61 m/s, and depth averaged 0.09 m. Riparian vegetation canopy closure averaged 70.9% across the transects.

Vegetation was the dominant aquatic macroinvertebrate habitat sampled along our monitoring site in 2012 (Figure 22). Vegetation accounted for 33.7% of the samples. Root wad was the next most abundant habitat type, at 32.5%. Rock represented 13.3% of the samples. Substrate fitting the category "Absence", meaning it lacked habitat that we define as appropriate for aquatic macroinvertebrates, occurred along 15.7% of the site. Both woody debris and leaf packs were found along 2.4% of GAR01.

Reach level. Gravels were the most abundant particle size found along the monitoring site in 2012 (Figure 23). Gravels accounted for 55.3% of the particles sampled. Sand was found along 19.0% of the monitoring site. Cobbles were found along 15.5% of the monitoring site. Bedrock accounted for 5.0% of the particles sampled. Four percent of the particles sampled were too cemented into the channel for measurement.

Run was the most abundant GCU found along our monitoring site in 2012, accounting for 83.1% of the categories sampled (Figure 24). Scour pools were found along 8.3% of the site, and cascades were found along 4.0% of the site. Riffles and dammed pools each accounted for 2.0% of the categories sampled. No chutes existed along our site in 2012.

Figure 22. Habitat characterization expressed as frequency of occurrence along transects from GAR01 at Garden Creek in GRCA, 2010–2012.

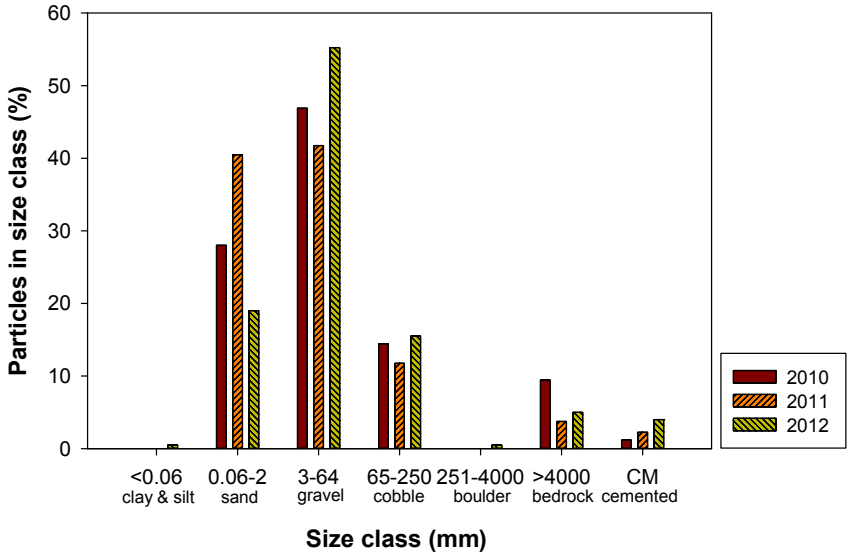


Figure 23. Particle size distribution from GAR01 at Garden Creek in GRCA, 2010–2012. Particles that are completely cemented into the stream channel preclude size measurements.

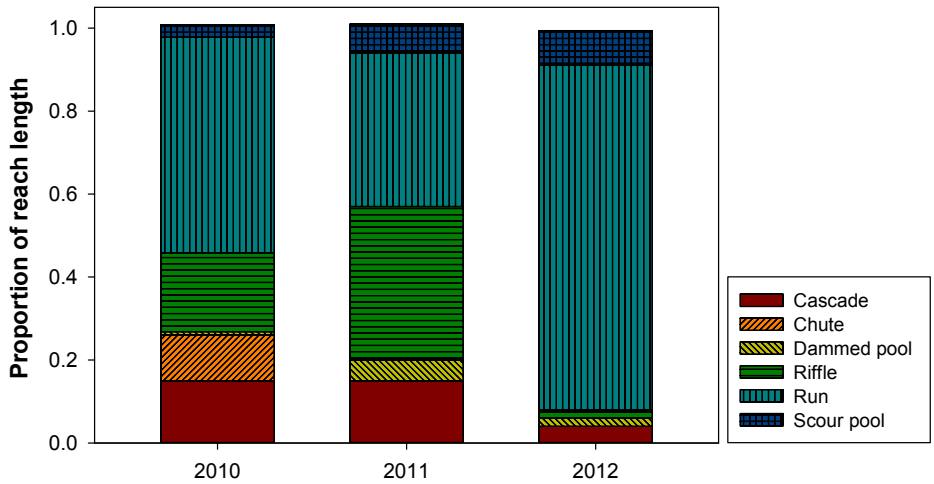


Figure 24. Geomorphic channel unit characterization of GAR01 at Garden Creek in GRCA, 2010–2012.

3.6 Hydrologic conditions for Garden Creek

3.6.1 SCPN water quality core parameter data

We report NPS core water quality measurements collected at or near midday of the sample date for Garden Creek in 2012. Data from all years of sampling at Garden Creek (2010–2012) are available in table format in Appendix F (Table F3). In 2012, the noon time water temperature was 15.7°C. Specific conductivity measured 304 µS/cm, and pH was 8.3. Dissolved oxygen measured 102.1% saturation and 8.9 mg/L. Turbidity was 14 NTU. Stream discharge at the time of our visit was 1.8 cfs.

3.6.2 NADP precipitation data

Precipitation values associated with Hermit Creek (Figure 14) are also applicable to Garden Creek.

3.7 Aquatic macroinvertebrate community data for Bright Angel Creek

We present key metrics calculated from sampling aquatic macroinvertebrate communities from 2010 to 2012 at BRI01. Figures in this section refer to quantitative data unless otherwise noted, and error bars in figures represent one standard deviation from the mean. All corresponding data values are available in table format in Appendix G (Tables G1, G2). Appendix D lists all aquatic macroinvertebrate species detected at the site, from both quantitative and qualitative methods.

Abundance. Mean total abundance values from quantitative targeted riffle samples at BRI01 averaged 738.40 individuals in 2012 (Figure 25). Sample abundances ranged from a low of 653 individuals to a high of 858.

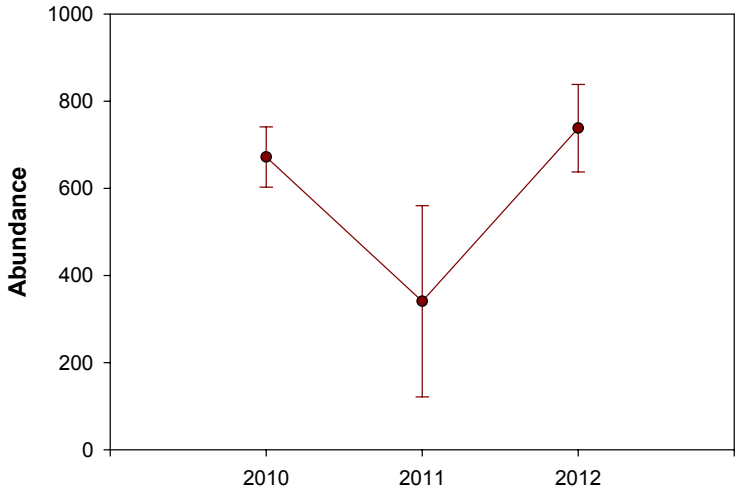


Figure 25. Aquatic macroinvertebrate abundance in samples from BRI01 at Bright Angel Creek in GRCA, 2010–2012.

Taxa richness. Total taxonomic richness from quantitative targeted riffle samples at BRI01 in 2012 averaged 17.60 taxa per sample (Figure 26). Quantitative samples ranged from a low of 14 taxa to a high of 20 taxa. Richness from our qualitative sample was 25 taxa.

Diversity. We used the Simpson's Diversity Index to measure both taxonomic and functional diversity of quantitative samples from BRI01 in 2012 (Figure 27). Taxonomic diversity averaged 0.80, and ranged from a low of 0.76 to a high of 0.84. Functional diversity was lower, averaging 0.37. Functional diversity ranged from a low of 0.28 to a high of 0.54.

Stress tolerance. Individuals intolerant to disturbance were the most abundant group at BRI01 in 2012, averaging 52.42% of the sample (Figure 28). Moderately tolerant individuals accounted for 47.36% of the sample. Few tolerant taxa (0.22%) were collected.

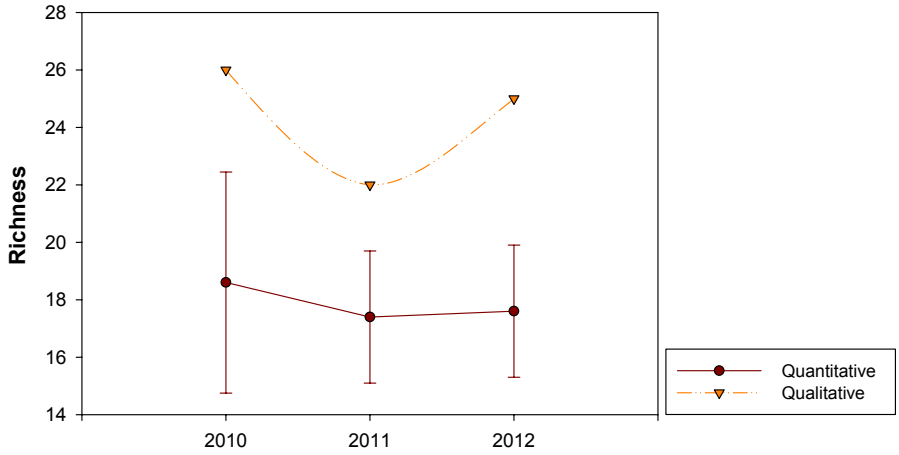


Figure 26. Taxa richness in quantitative and qualitative samples from BRI01 at Bright Angel Creek in GRCA, 2010–2012.

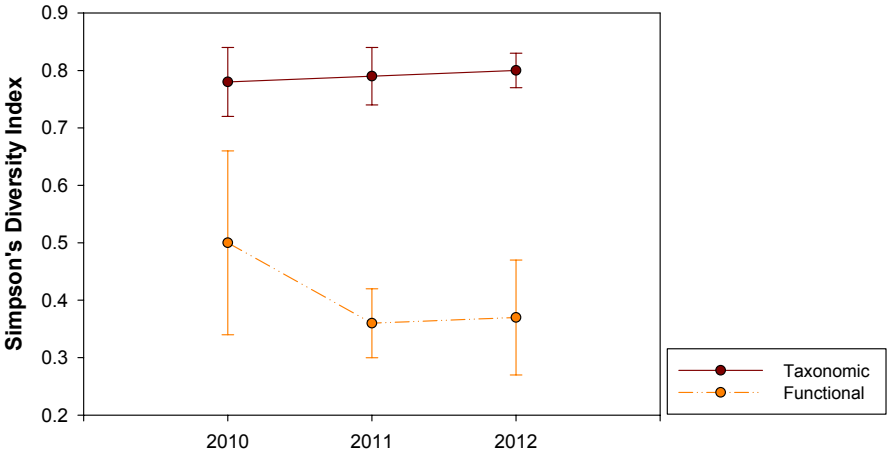


Figure 27. Taxonomic and functional diversity in samples from BRI01 at Bright Angel Creek in GRCA, 2010–2012.

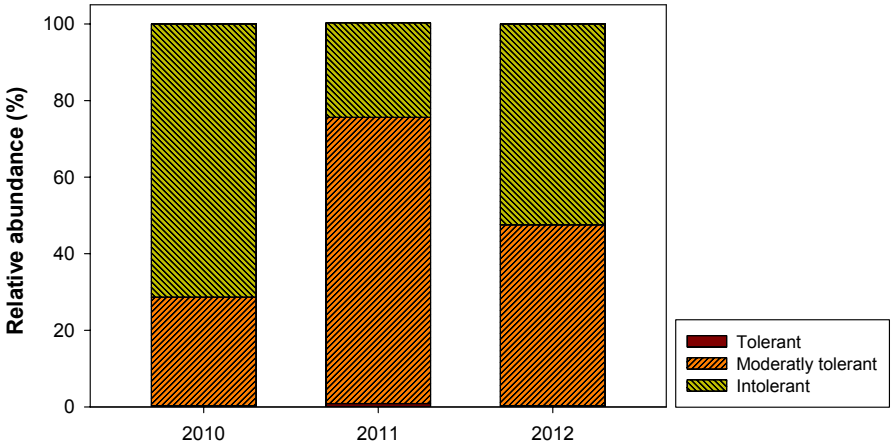


Figure 28. Mean relative abundance by tolerance group in aquatic macroinvertebrate samples from BRI01 at Bright Angel Creek in GRCA, 2010–2012. During all 3 years, tolerant taxa were <1%.

EPT taxa. The relative abundance of individuals in sensitive EPT orders was dominated by Ephemeroptera in 2012 (Figure 29). Ephemeroptera accounted for 41.96% of the individuals collected from BRI01 in 2012. Relative abundance of Trichoptera individuals was 6.45%. No Plecoptera were found during 2012.

Aquatic macroinvertebrate orders. Ephemeroptera was the most abundant group of aquatic macroinvertebrates collected from BRI01 in 2012, at 41.96% (Figure 30). Coleoptera was the next most abundant group, at 24.37%, followed by non-Chironomidae Diptera (9.98%), noninsect taxa (9.36%), Chironomidae (7.72%), Trichoptera (6.45%), and Odonata (0.15%).

Functional feeding groups. Collector-gatherers were the most abundant functional feeding group of aquatic macroinvertebrates in our 2012 samples (Figure 31). Relative abundance of collector-gatherers was 75.95%. Collector-filterers were the second most abundant, at 15.24%. Predators averaged 3.34%, and scrapers averaged 5.40%. Shredders were the least abundant, at 0.06%.

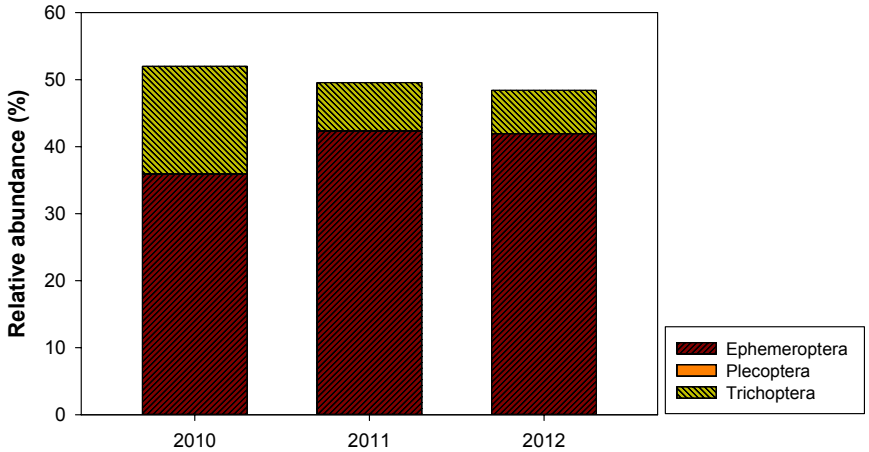


Figure 29. Mean relative abundance of aquatic macroinvertebrates belonging to sensitive EPT orders in samples from BRI01 at Bright Angel Creek in GRCA, 2010–2012. During all 3 years, Plectopera never comprised more than 0.1% of the samples.

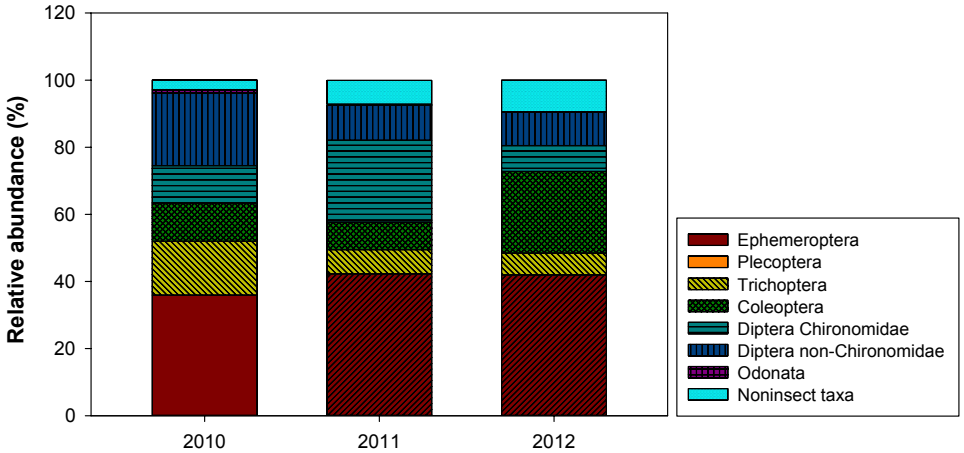


Figure 30. Mean relative abundance by taxonomic order in samples from BRI01 at Bright Angel Creek in GRCA, 2010–2012. During all 3 years, Plectopera never comprised more than 0.1% of the samples.

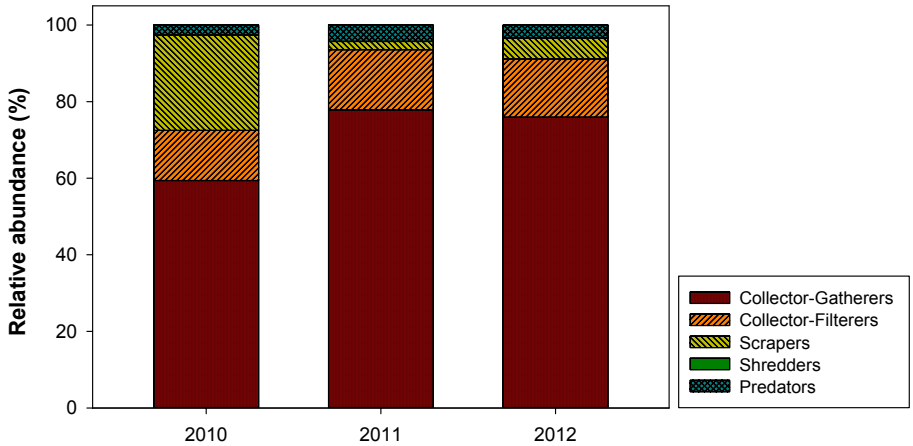


Figure 31. Mean relative abundance by functional feeding group in aquatic macroinvertebrate samples from BRI01 at Bright Angel Creek in GRCA, 2010–2012. During all 3 years, shredders never comprised more than 0.1% of the samples.

3.8 Physical habitat characteristics for Bright Angel Creek

Here we present data describing physical habitat characteristics collected at BRI01 from 2010 to 2012. These data are summarized in table format in Appendix G (Table G3); additional transect data can be found in Appendix E.

Microhabitat level. Stream flow velocity at the 5 targeted riffle sample locations averaged 0.68 m/s in 2012. Depths at these locations averaged 0.20 m. Individual particles were 48.0% embedded, on average.

Transect level. The average active channel width at the 11 physical habitat transects in 2012 was 15.1 m. Wetted channel width averaged 5.9 m. Velocity and depth averaged 0.54 m/s and 0.19 m, respectively.

Rock was the dominant habitat type and was found along 68.49% of the transects in 2012 (Figure 32). Vegetation was found along 2.74% of the transects. Substrate fitting the category "Absence", meaning it lacked habitat that we define as appropriate for aquatic macroinvertebrates, occurred along 28.77% of the site.

Reach level. Particle size distribution was dominated by gravel, which made up 33.5% of the particles sampled in 2012 (Figure 33). The next most abundant size class was cobble, comprising 31.5% of particles. Sand comprised 7.5% of the particles. Boulders comprised 10.8% of the sample. Clay & silt accounted for <1.0% of the particles sampled at the site. Cemented particles, those which we were unable to remove from the stream bottom, accounted for 11.5% of the particles sampled.

Cascades were the dominant GCU found along the monitoring site in 2012 (Figure 34). Cascades made up 52.1% of the site. Scour pools were the next most abundant, at 19.4%, followed by riffles at 15.1%, and runs at 13.4%.

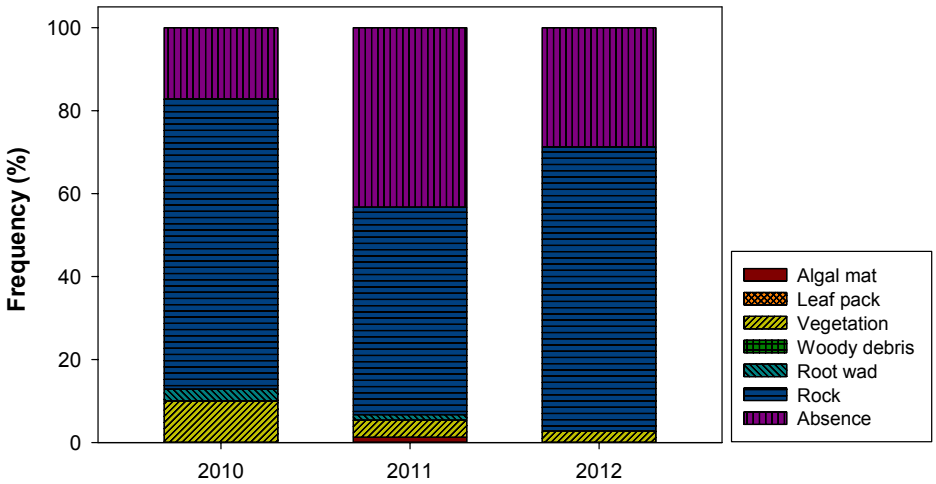


Figure 32. Habitat characterization expressed as frequency of occurrence along transects at BRI01 on Bright Angel Creek in GRCA, 2010–2012. Not all habitat structures were observed.

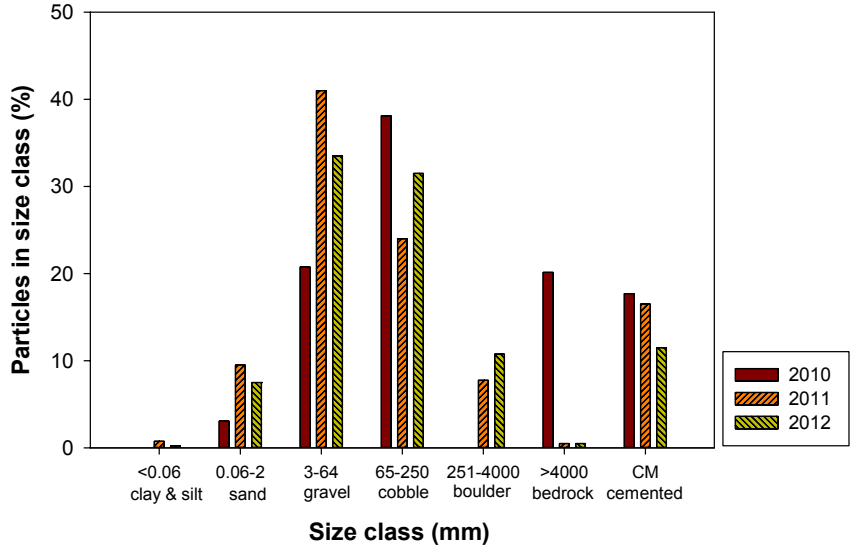


Figure 33. Particle size distribution along the reach at BRI01 at Bright Angel Creek in GRCA, 2010–2012. Particles that are completely cemented into the stream channel preclude size measurements.

Figure 34. Geomorphic channel unit characterization of BRI01 at Bright Angel Creek in GRCA, 2010–2012.

3.9 Hydrologic conditions for Bright Angel Creek

3.9.1 SCPN water quality core parameter data

We report NPS core water quality measurements collected at or near midday of the sample date for Bright Angel Creek in 2012. Data from all years of sampling at Bright Angel Creek (2010–2012) are available in table format in Appendix G (Table G3).

In 2012, the noon time water temperature was 14.4°C. Specific conductivity was 335 µS/cm and pH measured 8.8. Dissolved oxygen measured 102.1% saturation and 8.6 mg/L. Turbidity was 1.7 NTU. Stream discharge for the site at the time of our visit was 19.8 cfs.

3.9.2 USGS streamflow and temperature data

Figure 35 shows a hydrograph from the USGS streamflow gaging station, *Bright Angel Creek near Grand Canyon, AZ* (09403000) for the period 01 January 2012 to 31 December 2012 (USGS 2013). Increased flows follow the typical pattern of snowmelt in the early spring months and large pulses occurring during the summer monsoon months. The gage measured a maximum stream flow of 449.1 cfs on 03 August. The lowest flow recorded, 10.3 cfs, occurred on 16 June.

The USGS station also measured air and water temperatures from Bright Angel Creek every 15 minutes during 2012 (Figure 36). The average air temperature at Bright Angel Creek was 19.7°C. Air temperatures reached a high of 42.9°C on 21 June and a low of 1.7°C on 28 December. The average water temperature was 14.0°C. Water temperatures ranged from a high of 27.5°C on 07 August to a low of 3.9°C on 20 December.

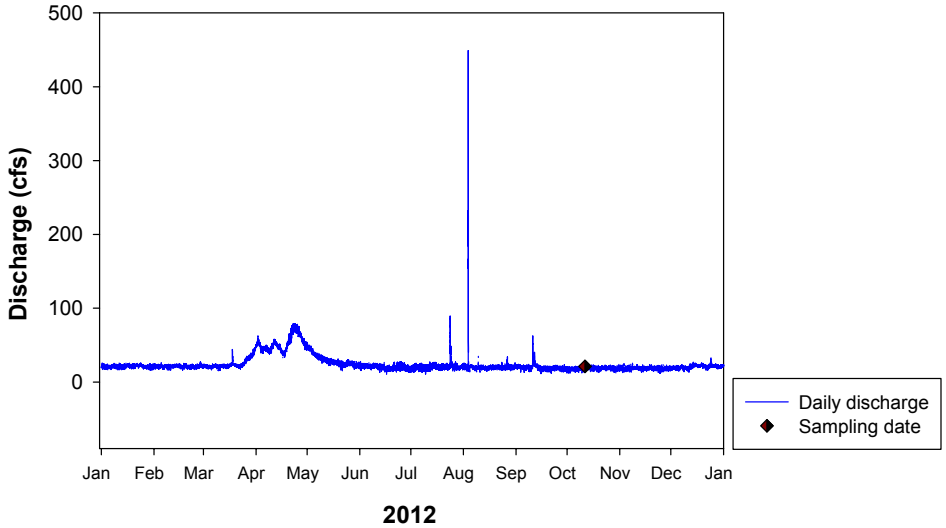


Figure 35. Discharge at Bright Angel Creek in 2012, from USGS streamflow gaging station #09403000.

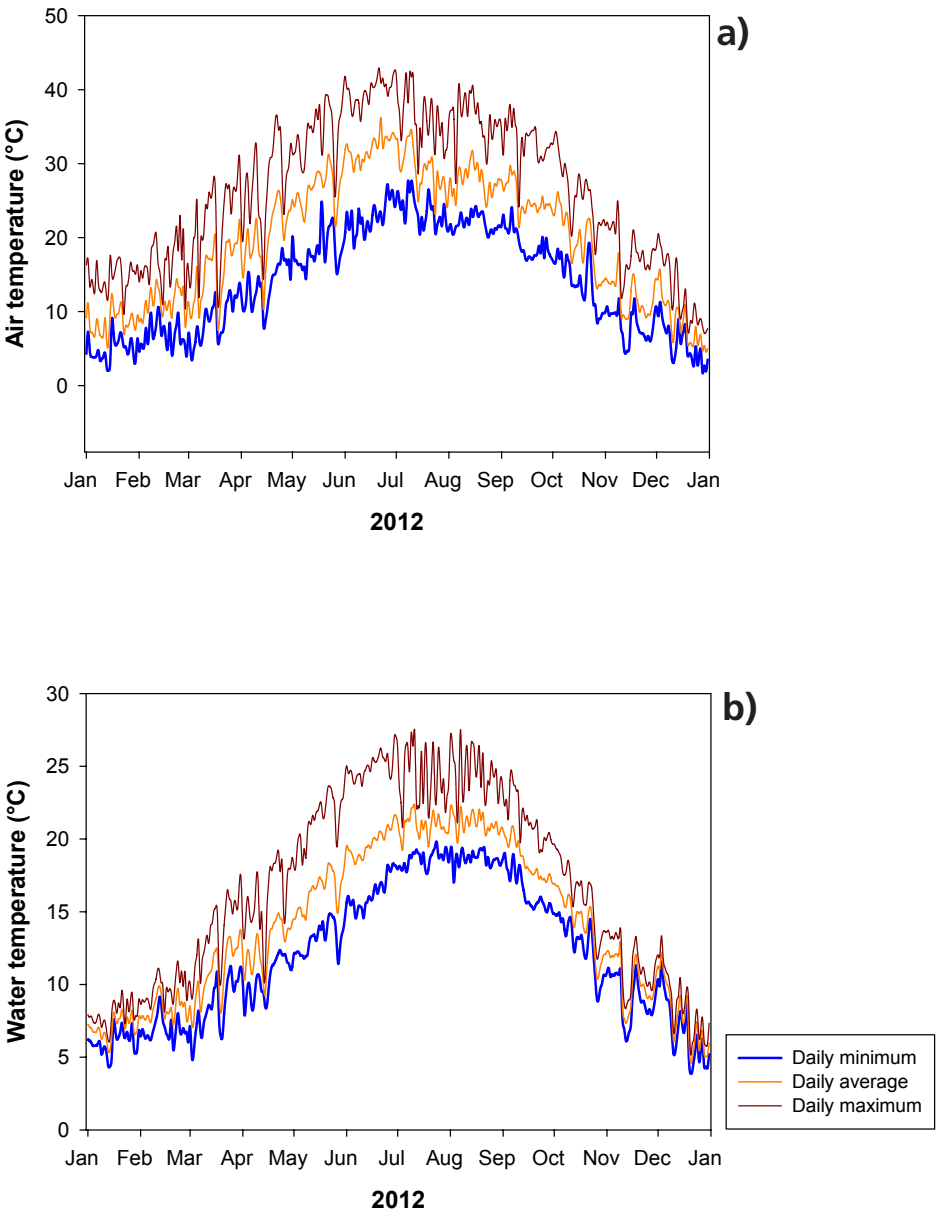


Figure 36. Air (a) and water (b) temperature recorded at 15 minute intervals in 2012 from Bright Angel Creek in GRCA, by USGS station #09403000.

4 Discussion

This report presents data from SCPN's fourth year of monitoring aquatic macroinvertebrates and physical habitat at Hermit Creek and the third year of monitoring at Garden Creek and Bright Angel Creek in Grand Canyon National Park, Arizona. We stress that the data included in this report are not to be interpreted as ecologically significant trends, as trends cannot be determined by a few years of sampling data.

Differences may be attributed to multiple factors, including ecological variability and sampling error, or may be a result of observer bias. SCPN attempts to minimize sampling error and observer bias by thoroughly training crew members in the proper field techniques prior to each sampling season.

In September 2011, a large storm event resulted in heavy rains and flash flooding throughout Grand Canyon National Park. Hermit and Bright Angel Creeks were both affected by the flash flooding. We collected post flood event data for Bright Angel Creek in fall 2011 (Stumpf and Monroe 2012b), and data included in this report represents the first dataset collected from Hermit Creek since the 2011 event.

Taxa richness at Hermit Creek declined from previous sampling years. Quantitative taxa richness averaged 21.00 taxa from 2009–2011 and 13.80 in 2012. Similarly, qualitative taxa richness declined from an average of 25 taxa from 2009–2011 to 11 in 2012. While abundance remained the same for all years, it is likely that the flood event that altered channel structures and habitat along the reach may be responsible for the loss of taxa. In 2012 we saw an increase in gravel particles and a decline in all aquatic macroinvertebrate habitat types along our monitoring reach. Our category "Absence", denoting the lack of suitable aquatic macroinvertebrate habitat, increased by 40% in 2012. All taxonomic orders, with the exception of Ephemeroptera, saw a decline in relative abundance in 2012 compared with previous sampling years. Likewise, the proportion of all geomorphic channel units decreased, with the exception of runs. Riparian cover was completely absent from our monitoring site in 2012. This was the first year where no riparian cover was found. Both of these habitat metrics suggest scouring of the reach, further strengthening the argument that the large flood event on 11 September 2011 affected the aquatic macroinvertebrate community.

Garden Creek was not affected by the storm event that led to large flows at Hermit and Bright Angel Creeks in 2011. Data collected in 2012 show that the aquatic macroinvertebrate community was dominated by Diptera species. Collector species were the dominant functional group, indicating that fine particulate matter in the water column and on bottom substrates was the primary energetic input being processed by the community. The low abundance of scrapers and shredders suggests that coarse particulate matter such as riparian vegetation is not being utilized by aquatic macroinvertebrates at Garden Creek.

Data collected in 2012 from Bright Angel Creek suggest that the aquatic macroinvertebrate community is recovering from the high flow event that occurred in 2011. In 2012 we saw an increase in abundance of aquatic macroinvertebrates in our quantitative targeted riffle samples compared with samples taken in 2011, and the abundance of sensitive intolerant taxa rebounded from their 2011 declines. Ephemeroptera continue to dominate quantitative samples at Bright Angel Creek. In 2012 we saw increases in the relative abundance of Coleoptera, specifically riffle beetles, and a decrease in Chironomidae taxa (disturbance tolerant). Riffle beetles can experience large declines during periods of high flows when their habitats are filled in with finer sediments. Once conditions improve (i.e., fine sediments get washed downstream), those numbers would be expected to increase. Channel structure data showing declines in finer sediments and cemented particles supports this pattern.

The data in this report should be viewed as a snapshot of conditions existing within the aquatic community at the time of our visit. Data and analyses in this report are provisional and are subject to change. When sufficient data are available, SCPN plans to produce an interpretive report including trend analysis of aquatic macroinvertebrate metrics and physical habitat data at monitored streams in Grand Canyon.

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Appendix A Southern Colorado Plateau Network aquatic macroinvertebrate monitoring sites on Bright Angel Creek, Garden Creek, and Hermit Creek in Grand Canyon National Park, Arizona, 2012

Site code	Common name	Report name	UTM Easting	UTM Northing	Elevation (m)
GRCABRI01	Bright Angel below first footbridge	BRI01	402061	9337091	821
GRCAGAR01	Garden Creek below Tonto Trail	GAR01	399029	3993992	1085
GRCAHER01	Hermit Creek below Tonto Trail	HER01	390736	3993596	865

Note: Horizontal coordinates are reported in Universal Transverse Mercator (UTM) Projection, Zone 12, North American Datum of 1983 (NAD 83). Vertical (elevation) coordinates are referenced to the North American Vertical Datum of 1988 (NAVD 88).

Appendix B Selected aquatic macroinvertebrate metrics

Metric type	Metric	Definition
Abundance/Richness/ Diversity	Total abundance	Total number of individuals.
	Taxa richness	Total number of taxa (measures the overall variety of aquatic macroinvertebrates in a sample).
	Simpson's diversity	A measure of the variety of taxa that takes into account the relative abundance of each taxon. $D = \sum(n_i(n_i - 1)/N(N-1))$
Tolerance	Dominant taxa	Measures the dominance of the most abundant taxa. Typically calculated as dominant 2, 3, 4, or 5 taxa.
	Relative abundance tolerant taxa	Percent of individuals considered to be sensitive to perturbation.
	Percent richness of tolerant taxa	Percent of taxa considered to be sensitive to perturbation.
Functional-Feeding	Relative abundance collector-filterers	Percent of individuals that filter fine particulate organic matter from the water column.
	Percent richness collector-filterers	Percent of taxa that filter fine particulate matter from the water column.
	Relative abundance scrapers	Percent of individuals that scrape or graze upon periphyton.
Functional-Habit	Relative abundance burrowers	Percent of individuals that move between substrate particles (typically fine substrates).
	Percent richness burrowers	Percent of taxa that move between substrate particles (typically fine substrates).
	Relative abundance clingers	Percent of individuals that have fixed retreats or adaptations for attachment to surfaces in flowing water.
	Percent richness clingers	Percent of taxa that have fixed retreats or adaptations for attachment to surfaces in flowing water.
Composition	Number of EPT taxa	Number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies).
	Relative abundance EPT	Percent of individuals in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies).
	Relative abundance Ephemeroptera	Percent of individuals that are mayflies.
	Relative abundance Plecoptera	Percent of individuals that are stoneflies (for streams >1,500 m in elevation).
	Relative abundance Trichoptera	Percent of individuals that are caddisflies.
	Hydroptilidae+ Hydropsychidae/Trichoptera	Percent of trichopteran individuals in Hydroptilidae plus Hydropsychidae (ratio of tolerant caddisfly abundance to total caddisfly abundance).
	Relative abundance noninsect taxa	Percent of individuals that are not insects.
	Relative abundance Chironomidae	Percent of individuals that are midges.

Source: Data from Brasher et al. (2011)

Appendix C Aquatic macroinvertebrate community and physical habitat data from the aquatic macroinvertebrate monitoring site on Hermit Creek in Grand Canyon National Park, Arizona, 2009–2012

Table C1. Quantitative aquatic macroinvertebrate community metrics from HER01 on Hermit Creek in Grand Canyon NP. For a given order, tolerance or functional feeding group, abundance-based metrics are expressed as the percentage of individuals in the group, while richness-based metrics for all years are expressed as the percentage of taxa in the group.

	2009 (*n* = 5)		2010 (*n* = 5)		2011 (*n* = 5)		2012 (*n* = 5)	
Quantitative metric	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Total abundance	603.40	60.04	510.00	150.28	675.00	57.22	768.40	113.49
Total richness	20.20	1.64	17.60	3.05	21.00	2.45	13.80	2.17
Simpson's Diversity—taxonomic	0.69	0.08	0.73	0.06	0.78	0.06	0.41	0.19
Simpson's Diversity—functional group	0.35	0.15	0.22	0.07	0.28	0.11	0.12	0.03
Dominant taxa	46.91	10.51	44.80	10.48	34.65	11.62	72.54	15.53
Tolerance group								
Relative abundance of tolerant taxa (%)	16.83	20.65	2.17	1.05	1.74	1.14	0.81	0.42
Relative abundance of moderately tolerant taxa (%)	45.25	19.14	60.02	20.55	54.54	21.33	80.64	13.69
Relative abundance of intolerant taxa (%)	37.92	16.69	37.80	20.70	43.72	21.10	18.55	13.55
Richness of tolerant taxa (%)	22.56	4.44	18.05	7.37	17.94	3.80	17.15	7.37
Richness of moderately tolerant taxa (%)	46.06	3.26	53.31	5.09	56.40	5.40	50.58	7.06
Richness of intolerant taxa (%)	31.38	3.51	28.64	6.14	25.66	6.45	32.27	6.36
Functional group								
Relative abundance of collector-filterers (%)	2.89	1.85	5.18	5.00	7.82	6.91	4.85	1.19
Relative abundance of collector-gatherers (%)	72.97	20.60	87.53	4.38	83.74	7.85	93.46	1.86
Relative abundance of scrapers (%)	0.72	0.49	0.80	0.49	0.77	0.60	0.00	0.00
Relative abundance of shredders (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.11
Relative abundance of predators (%)	23.42	20.36	6.50	2.20	7.67	2.51	1.62	1.22
Richness of collector-filterers (%)	10.48	4.02	10.68	3.81	9.80	1.07	15.12	1.99
Richness of collector-gatherers (%)	33.33	3.93	42.60	6.40	43.05	5.43	50.83	6.84
Richness of scrapers (%)	5.24	0.43	9.43	4.08	5.79	4.20	0.00	0.00
Richness of shredders (%)	0.00	0.00	0.00	0.00	0.00	0.00	3.15	4.40
Richness of predators (%)	50.95	4.14	37.29	9.75	41.36	8.12	30.89	6.39
Taxonomic group								
Number of EPT taxa	4.40	0.55	4.80	0.45	4.80	1.64	3.60	0.55
Relative abundance of EPT taxa (%)	4.43	1.59	20.42	13.39	36.12	13.30	89.70	3.87
Relative abundance of Ephemeroptera (%)	2.59	1.10	16.47	11.89	31.91	14.73	89.07	4.15
Relative abundance of Plecoptera (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Relative abundance of Trichoptera (%)	1.84	0.98	3.95	4.62	4.21	5.22	0.63	0.44
Relative abundance of noninsect taxa (%)	6.66	3.91	4.62	1.68	4.88	2.10	0.33	0.23
Relative abundance of Chironomidae Diptera (%)	38.69	19.29	40.06	13.16	33.35	9.99	3.45	1.88
Relative abundance of non-Chironomidae Diptera (%)	17.31	20.15	9.80	9.29	12.41	10.24	5.16	1.26
Relative abundance of Coleoptera (%)	31.96	16.70	24.51	23.95	11.75	12.80	1.26	1.03
Relative abundance of Odonata (%)	0.96	0.81	0.58	0.55	1.49	1.13	0.10	0.21

Table C2. Qualitative aquatic macroinvertebrate community metrics from HER01 on Hermit Creek in Grand Canyon NP. Richness-based metrics are expressed as the percentage of taxa in a given order, tolerance or functional feeding group.

Qualitative metric	2009	2010	2011	2012
Taxa richness	23	27	25	11
Tolerance group				
Richness of tolerant taxa (%)	28.57	24.00	18.18	20.00
Richness of moderately tolerant taxa (%)	47.62	48.00	50.00	60.00
Richness of intolerant taxa (%)	23.81	28.00	31.82	20.00
Functional group				
Richness of collector-filterers (%)	9.09	7.69	8.33	10.00
Richness of collector-gatherers (%)	31.82	46.15	37.50	50.00
Richness of scrapers (%)	4.55	3.85	4.17	0.00
Richness of shredders (%)	0.00	3.85	4.17	0.00
Richness of predators (%)	54.55	38.46	45.83	40.00
Taxonomic group				
Number of EPT taxa	4	7	5	2
Richness of EPT taxa (%)	17.39	25.93	20.00	18.18
Richness of Ephemeroptera (%)	8.70	11.11	12.00	18.18
Richness of Plecoptera (%)	0.00	0.00	0.00	0.00
Richness of Trichoptera (%)	8.70	14.81	8.00	0.00
Richness of noninsect taxa (%)	21.74	18.52	20.00	9.10
Richness of Chironomidae Diptera (%)	13.04	11.11	12.00	27.27
Richness of non-Chironomidae Diptera (%)	34.78	29.63	32.00	18.18
Richness of Coleoptera (%)	4.35	7.41	8.00	18.18
Richness of Odonata (%)	8.70	7.41	8.00	9.09

Table C3. Physical habitat and hydrologic data from HER01 on Hermit Creek in Grand Canyon NP, Arizona, 2009–2012. Particle embeddedness and canopy closure measurements are expressed as percentages.

	2009		2010		2011		2012	
Physical habitat metric	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Microhabitat level (*n* = 5)								
Riffles								
Velocity (m/s)	0.42	0.15	0.46	0.33	0.58	0.18	0.59	0.20
Depth (m)	0.08	0.02	0.11	0.04	0.16	0.13	0.07	0.02
Embeddedness (%)	25.7	20.2	53.1	30.7	16.1	7.5	18.0	12.0
Transect level (*n* = 11)								
Channel dimensions								
Velocity (m/s)	0.18	0.11	0.15	0.09	0.14	0.12	0.17	0.14
Depth (m)	0.08	0.04	0.08	0.07	0.11	0.08	0.05	0.03
Wetted channel width (m)	1.9	0.7	2.7	1.1	2.2	1.1	3.4	2.8
Active channel width (m)	10.0	2.4	7.0	2.4	9.2	2.9	4.7	6.5
Riparian cover								
Canopy closure (%)	14.4	27.9	7.5	20.5	6.6	14.6	0.0	0.0
Reach level (*n* = 1)								
Water quality	**Value**		**Value**		**Value**		**Value**	
Temperature (°C)	17.4		15.6		13.3		16.7	
Specific conductivity (µS/cm)	429		575		435		442	
pH	8.4		8.7		8.6		8.4	
Dissolved oxygen (% saturation)	111.0		—		100.9		99.9	
Dissolved oxygen (mg/L)	11.1		—		9.5		8.7	
Turbidity (NTU)	0.41		0.30		—		5.8	
Discharge (cfs)	—		—		0.8		0.6	

Appendix D Aquatic macroinvertebrate species list from aquatic macroinvertebrate monitoring sites on Bright Angel Creek, Garden Creek, and Hermit Creek in Grand Canyon National Park, Arizona, 2012

Phylum	Class	Order	Family	SubFamily	Genus	Species	Common name	Funct group[1]	Tol group[2]	HER01	GAR01	BRI01
Annelida	Clitellata						segmented worms	coll-gath	n/a		x	x
Arthropoda	Arachnida	Trombidiformes	Arrenuridae		*Arrenurus* sp.		water mites	pred	n/a		x	
Arthropoda	Arachnida	Trombidiformes	Lebertiidae		*Lebertia* sp.		water mites	pred	tol			NEW
Arthropoda	Arachnida	Trombidiformes	Sperchonidae		*Sperchon* sp.		water mites	pred	tol	x	x	x
Arthropoda	Arachnida	Trombidiformes	Sperchonidae		*Sperchonopsis* sp.		water mites	pred	tol			NEW
Arthropoda	Arachnida	Trombidiformes	Sperchonidae				water mites	pred	tol	x	x	x
Arthropoda	Arachnida	Trombidiformes	Torrenticolidae		*Torrenticola* sp.		water mites	pred	none		x	
Arthropoda	Arachnida	Trombidiformes					water mites	n/a	n/a	x	x	x
Arthropoda	Insecta	Coleoptera	Dytiscidae				predaceous diving beetle	pred	mod tol			
Arthropoda	Insecta	Coleoptera	Haliplidae		*Peltodytes* sp.		crawling water beetles	shredder	mod tol		x	
Arthropoda	Insecta	Coleoptera	Elmidae		*Heterelmis* sp.		riffle beetles	coll-gath	intol		NEW	
Arthropoda	Insecta	Coleoptera	Elmidae		*Microcylloepus*	*pusillus*	riffle beetles	coll-gath	intol	x	x	x
Arthropoda	Insecta	Coleoptera	Elmidae				riffle beetles	coll-gath	intol	x	x	x
Arthropoda	Insecta	Coleoptera	Hydraenidae		*Ochthebius* sp.		minute moss beetles	n/a	n/a	NEW		NEW
Arthropoda	Insecta	Diptera	Empididae	Hemerodromiinae	*Hemerodromia* sp.		dance flies	pred	mod tol	x		NEW
Arthropoda	Insecta	Diptera	Empididae		*Clinocera* sp.		dance flies	pred	mod tol	NEW		
Arthropoda	Insecta	Diptera	Empididae		*Neoplasta* sp.		dance flies	pred	mod tol	x		
Arthropoda	Insecta	Diptera	Empididae		*Wiedemannia*		dance flies	pred	mod tol			x
Arthropoda	Insecta	Diptera	Empididae				dance flies	pred	mod tol	x		
Arthropoda	Insecta	Diptera	Muscidae				house flies	pred	mod tol	x	x	
Arthropoda	Insecta	Diptera	Stratiomyidae		*Caloparyphus* sp.		solider flies	coll-gath	mod tol	x		
Arthropoda	Insecta	Diptera	Stratiomyidae		*Euparyphus* sp.		solider flies	coll-gath	n/a	x		
Arthropoda	Insecta	Diptera	Stratiomyidae				solider flies	coll-gath	tol	x		
Arthropoda	Insecta	Diptera	Tabanidae		*Tabanus* sp.		horse flies	pred	mod tol		x	x
Arthropoda	Insecta	Diptera	Ceratopogonidae	Ceratopogoninae	*Probezzia* sp.		biting midges	pred	mod tol		x	x
Arthropoda	Insecta	Diptera	Ceratopogonidae	Forcipomyiinae	*Atrichopogon* sp.		biting midges	pred	mod tol	NEW		
Arthropoda	Insecta	Diptera	Ceratopogonidae				biting midges	pred	mod tol		x	
Arthropoda	Insecta	Diptera	Chironomidae	Chironominae			midges	coll-gath	mod tol	x	x	x
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladiinae			midges	coll-gath	mod tol	x	x	x

Phylum	Class	Order	Family	SubFamily	Genus	Species	Common name	Funct group[1]	Tol group[2]	HER01	GAR01	BRI01
Arthropoda	Insecta	Diptera	Chironomidae	Tanypodinae			midges	pred	tol	x	x	x
Arthropoda	Insecta	Diptera	Chironomidae				midges	coll-gath	mod tol	x	x	x
Arthropoda	Insecta	Diptera	Dixidae		*Dixa* sp.		meniscus midges	coll-gath	intol	x		x
Arthropoda	Insecta	Diptera	Dixidae				meniscus midges	coll-gath	intol			NEW
Arthropoda	Insecta	Diptera	Psychodidae		*Maruina* sp.		moth flies	scraper	intol			x
Arthropoda	Insecta	Diptera	Simuliidae	Simuliinae	*Simulium* sp.		black flies	coll-filt	mod tol	x	x	x
Arthropoda	Insecta	Diptera	Simuliidae				black flies	coll-filt	mod tol	x	x	x
Arthropoda	Insecta	Diptera	Tipulidae	Limoniinae	*Limonia* sp.		crane flies	shredder	mod tol			NEW
Arthropoda	Insecta	Diptera	Tipulidae	Tipulinae	*Tipula* sp.		crane flies	shredder	mod tol	NEW	x	
Arthropoda	Insecta	Diptera	Tipulidae		*Dicranota* sp.		crane flies	pred	intol	NEW		
Arthropoda	Insecta	Diptera	Tipulidae				crane flies	shredder	intol		x	
Arthropoda	Insecta	Diptera					flies	n/a	mod tol	x	x	
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae		*Paraleptophlebia* sp.		pronggilled mayflies	coll-gath	intol		x	
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae				pronggilled mayflies	coll-gath	intol		x	x
Arthropoda	Insecta	Ephemeroptera	Baetidae		*Baetis* sp.		small minnow mayflies	coll-gath	mod tol	x	x	x
Arthropoda	Insecta	Ephemeroptera	Baetidae		*Baetodes* sp.		small minnow mayflies	coll-gath	intol	x	x	x
Arthropoda	Insecta	Ephemeroptera	Baetidae		*Fallceon*	*quilleri*	small minnow mayflies	coll-gath	n/a	x	x	x
Arthropoda	Insecta	Ephemeroptera	Baetidae				small minnow mayflies	coll-gath	intol	x	x	x
Arthropoda	Insecta	Ephemeroptera	Heptageniidae				flatheaded mayflies	scraper	intol			NEW
Arthropoda	Insecta	Hemiptera	Veliidae	Microveliinae	*Microvelia* sp.		smaller water striders	pred	mod tol			NEW
Arthropoda	Insecta	Lepidoptera	Crambidae	Nymphulinae	*Petrophila* sp.		crambid snout moths	scraper	intol		x	x
Arthropoda	Insecta	Megaloptera	Corydalidae	Corydalinae	*Corydalus*	*cornutus*	eastern dobsonfly	pred	mod tol		x	x
Arthropoda	Insecta	Odonata	Libellulidae				skimmers	pred	tol			x
Arthropoda	Insecta	Odonata	Aeshnidae		*Oplonaeschna* sp.		darners	pred	intol		NEW	
Arthropoda	Insecta	Odonata	Aeshnidae				darners	pred	intol	x		
Arthropoda	Insecta	Odonata	Calopterygidae		*Hetaerina* sp.		rubyspot broad-winged damselflies	pred	mod tol		x	x
Arthropoda	Insecta	Odonata	Calopterygidae				broad-winged dam-selflies	pred	mod tol			x
Arthropoda	Insecta	Odonata	Coenagrionidae		*Argia* sp.		narrow-winged dam-selflies	pred	mod tol		x	x
Arthropoda	Insecta	Odonata	Coenagrionidae				narrow-winged dam-selflies	pred	tol	x	x	x
Arthropoda	Insecta	Odonata					damselflies/dragonflies	pred	n/a	x		
Arthropoda	Insecta	Trichoptera	Brachycentridae		*Micrasema* sp.		humpless casemaker caddisflies	n/a	intol		x	

Phylum	Class	Order	Family	SubFamily	Genus	Species	Common name	Funct group[1]	Tol group[2]	HER01	GAR01	BRI01
Arthropoda	Insecta	Trichoptera	Helicopsychidae		*Helicopsyche* sp.		snail-case caddisflies	scraper	intol		x	x
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsychinae	*Hydropsyche* sp.		netspinning caddisflies	coll-filt	intol	x		x
Arthropoda	Insecta	Trichoptera	Hydropsychidae				netspinning caddisflies	coll-filt	intol	x	x	x
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptilinae	*Leucotrichia* sp.		ring horn microcad-disflies	scraper	mod tol			x
Arthropoda	Insecta	Trichoptera	Hydroptilidae				microcaddisflies	n/a	intol		x	
Arthropoda	Insecta	Trichoptera	Leptoceridae	Leptocerinae	*Oecetis* sp.		long-horned caddisflies	pred	mod tol		NEW	
Arthropoda	Insecta	Trichoptera	Limnephilidae				northern caddisflies	shredder	intol	NEW		
Arthropoda	Insecta	Trichoptera	Philopotamidae	Chimarrinae	*Chimarra* sp.		little black caddisflies	coll-filt	intol		x	x
Arthropoda	Insecta	Trichoptera	Philopotamidae				fingernet caddisflies	coll-filt	intol			x
Arthropoda	Insecta	Trichoptera	Psychomyiidae				net tube caddisflies	coll-gath	n/a			NEW
Arthropoda	Insecta	Trichoptera	Rhyacophilidae		*Rhyacophila*	*coloradensis*	green sedge caddisflies	pred	n/a			x
Arthropoda	Insecta	Trichoptera	Rhyacophilidae		*Rhyacophila* sp.		green sedge caddisflies	pred	intol			x
Arthropoda	Insecta	Trichoptera					caddisflies	n/a	n/a	x	x	
Arthropoda	Malacostraca	Isopoda					isopods	coll-gath	n/a		NEW	
Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidiinae	*Pisidium* sp.		freshwater clams	coll-filt	mod tol			NEW
Mollusca	Gastropoda	Basommatophora	Lymnaeidae	Lymnaeinae	*Lymnaea* sp.		freshwater snails	scraper	mod tol		x	
Nemata							roundworms	n/a	n/a		x	NEW
Platyhel-minthes	Turbellaria						flatworms	pred	intol		x	

Note: "NEW" under the site column denotes a new record for this SCPN monitoring site.
[1]Functional group abbreviations: coll-gath = collector-gatherer, coll-filt = coll-filterer, pred = predator.
[2]Tolerance group abbreviations: tol = tolerant, mod tol = moderately tolerant, intol = intolerant.

Appendix E Measured stream velocity and channel characteristics from aquatic macroinvertebrate monitoring sites on Bright Angel Creek, Garden Creek, and Hermit Creek in Grand Canyon National Park, Arizona, 2012

	Velocity (m/s) (n = 5)		Depth (m) (n = 5)		Wetted channel width (m)	Active channel width (m)
Transect	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Value**	**Value**
HER01						
1	0.00	0.00	0.01	0.01	9.7	—
2	0.06	0.13	0.01	0.03	7.7	17.4
3	0.50	0.17	0.06	0.03	1.0	15.4
4	0.15	0.24	0.03	0.05	2.4	—
5	0.32	0.13	0.04	0.01	2.4	—
6	0.25	0.15	0.05	0.02	1.7	—
7	0.08	0.08	0.06	0.05	2.5	5.4
8	0.13	0.03	0.12	0.03	1.5	7.0
9	0.17	0.08	0.07	0.05	1.2	7.1
10	0.08	0.19	0.08	0.18	4.4	—
11	0.16	0.21	0.03	0.03	3.1	—
GAR01						
1	0.47	0.34	0.07	0.02	2.3	9.7
2	0.59	0.42	0.09	0.05	1.4	7.9
3	0.65	0.12	0.09	0.03	1.5	9.8
4	0.29	0.38	0.07	0.05	2.3	10.1
5	0.77	0.32	0.06	0.02	1.3	12.8
6	0.80	0.56	0.08	0.06	0.8	11.7
7	0.52	0.16	0.14	0.04	0.8	9.0
8	0.49	0.28	0.13	0.15	1.0	12.4
9	1.00	0.25	0.07	0.05	1.0	11.5
10	0.50	0.19	0.08	0.05	2.0	10.7
11	0.58	0.23	0.06	0.06	1.6	13.0
BRI01						
1	0.68	0.72	0.07	0.07	8.2	23.5
2	0.22	0.39	0.07	0.10	8.9	14.6
3	0.62	0.54	0.19	0.13	5.3	14.4
4	0.40	0.05	0.28	0.14	3.9	10.0
5	0.37	0.32	0.11	0.09	8.7	15.4
6	0.49	0.51	0.15	0.09	7.8	17.5
7	0.48	0.25	0.26	0.14	4.3	10.8
8	1.02	0.42	0.26	0.05	5.1	13.7
9	0.67	0.71	0.14	0.15	4.6	15.4
10	0.47	0.26	0.44	0.05	3.7	17.3
11	0.50	0.83	0.15	0.08	4.9	13.3

Appendix F Aquatic macroinvertebrate community and physical habitat data from the aquatic macroinvertebrate monitoring site on Garden Creek in Grand Canyon National Park, Arizona, 2009–2012

Table F1. Quantitative aquatic macroinvertebrate community metrics from GAR01 on Garden Creek in Grand Canyon NP. For a given order, tolerance or functional feeding group, abundance-based metrics are expressed as the percentage of individuals in the group, while richness-based metrics for all years are expressed as the percentage of taxa in the group.

	2010 (*n* = 5)		2011 (*n* = 5)		2012 (*n* = 5)	
Quantitative metric	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Total abundance	696.00	39.40	706.80	64.69	727.40	59.96
Total richness	23.60	1.82	19.20	1.48	18.20	2.49
Simpson's Diversity—taxonomic	0.84	0.04	0.74	0.05	0.77	0.04
Simpson's Diversity—functional group	0.47	0.07	0.49	0.06	0.47	0.05
Dominant taxa	28.38	9.11	38.10	9.41	32.08	3.71
Tolerance group						
Relative abundance of tolerant taxa (%)	1.93	0.85	1.56	0.79	0.60	0.60
Relative abundance of moderately tolerant taxa (%)	68.31	8.27	88.07	6.84	87.38	6.85
Relative abundance of intolerant taxa (%)	29.76	8.16	10.37	7.31	12.02	6.73
Richness of tolerant taxa (%)	8.22	3.22	11.96	6.09	6.45	0.97
Richness of moderately tolerant taxa (%)	56.08	6.10	59.47	6.40	53.76	7.12
Richness of intolerant taxa (%)	35.69	6.06	28.58	3.92	39.79	7.80
Functional group						
Relative abundance of collector-filterers (%)	15.25	3.17	31.67	16.55	31.81	7.62
Relative abundance of collector-gatherers (%)	70.15	6.35	60.61	14.85	64.77	7.31
Relative abundance of scrapers (%)	8.27	4.88	1.03	0.93	0.14	0.26
Relative abundance of shredders (%)	0.09	0.13	0.24	0.19	0.30	0.23
Relative abundance of predators (%)	6.25	2.67	6.45	2.00	2.97	0.47
Richness of collector-filterers (%)	14.40	4.83	20.07	3.27	20.55	1.81
Richness of collector-gatherers (%)	35.55	3.48	27.72	5.65	38.98	6.35
Richness of scrapers (%)	8.51	0.64	8.87	4.86	2.11	2.90
Richness of shredders (%)	2.62	4.01	5.84	4.44	6.14	0.96
Richness of predators (%)	38.91	5.79	37.50	8.55	32.22	7.69
Taxonomic group						
Number of EPT taxa	7.80	1.48	5.40	1.52	5.40	1.95
Relative abundance of EPT taxa (%)	58.52	4.41	37.02	10.98	29.14	4.09
Relative abundance of Ephemeroptera (%)	44.49	7.95	31.43	12.28	23.96	3.03
Relative abundance of Plecoptera (%)	0.00	0.00	0.00	0.00	0.00	0.00
Relative abundanceof Trichoptera (%)	14.03	4.60	5.59	3.14	5.19	5.30
Relative abundance of noninsect taxa (%)	4.38	1.85	2.77	1.25	1.71	0.68
Relative abundance of Chironomidae Diptera (%)	22.88	2.95	25.70	5.39	33.52	6.28
Relative abundance of non-Chironomidae Diptera (%)	11.86	3.02	27.58	15.49	28.08	6.49
Relative abundance of Coleoptera (%)	1.63	1.41	4.27	4.79	5.91	5.15
Relative abundance of Odonata (%)	0.73	0.36	2.66	0.92	1.63	0.54

Table F2. Qualitative aquatic macroinvertebrate community metrics from GAR01 on Garden Creek in Grand Canyon NP. Richness-based metrics are expressed as the percentage of taxa in a given order, tolerance or functional feeding group.

Qualitative metric	2010	2011	2012
Taxa richness	28	20	27
Tolerance group			
Richness of tolerant taxa (%)	7.41	6.25	8.70
Richness of moderately tolerant taxa (%)	48.15	56.25	56.52
Richness of intolerant taxa (%)	44.44	37.50	34.78
Functional group			
Richness of collector-filterers (%)	18.52	18.75	16.67
Richness of collector-gatherers (%)	33.33	31.25	25.00
Richness of scrapers (%)	11.11	0.00	8.33
Richness of shredders (%)	3.70	6.25	8.33
Richness of predators (%)	33.33	43.75	41.67
Taxonomic group			
Number of EPT taxa	10	5	7
Richness of EPT taxa (%)	35.71	25.00	25.93
Richness of Ephemeroptera (%)	14.29	10.00	3.70
Richness of Plecoptera (%)	0.00	0.00	0.00
Richness of Trichoptera (%)	21.43	15.00	22.22
Richness of noninsect taxa (%)	14.29	30.00	25.93
Richness of Chironomidae Diptera (%)	10.71	15.00	11.11
Richness of non-Chironomidae Diptera (%)	25.00	10.00	18.52
Richness of Coleoptera (%)	7.14	10.00	7.41
Richness of Odonata (%)	7.14	10.00	11.11

Table F3. Physical habitat and hydrologic data from GAR01 on Garden Creek in Grand Canyon NP, Arizona, 2009–2012. Particle embeddedness and canopy closure measurements are expressed as percentages.

	2010		2011		2012	
Physical habitat metric	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Microhabitat level (*n* = 5)						
Riffles						
Velocity (m/s)	0.75	0.21	0.70	0.15	0.84	0.33
Depth (m)	0.13	0.02	0.16	0.04	0.10	0.03
Embeddedness (%)	34.1	16.0	33.6	10.1	20.8	8.8
Transect level (*n* = 11)						
Channel dimensions						
Velocity (m/s)	0.59	0.25	0.39	0.12	0.61	0.19
Depth (m)	0.08	0.02	0.09	0.04	0.09	0.03
Wetted channel width (m)	1.3	0.3	1.5	0.5	1.4	0.5
Active channel width (m)	6.6	2.7	11.0	2.1	10.8	1.6
Riparian cover						
Canopy closure (%)	70.8	28.6	64.2	34.5	70.9	27.0
Reach level (*n* = 1)						
Water quality	**Value**		**Value**		**Value**	
Temperature (°C)	15.3		15.2		15.7	
Specific conductivity (µS/cm)	—		267		304	
pH	8.9		8.6		8.3	
Dissolved oxygen (% saturation)	—		96.5		102.1	
Dissolved oxygen (mg/L)	—		8.5		8.9	
Turbidity (NTU)	—		8.3		14	
Discharge (cfs)	—		2.3		1.8	

Appendix G Aquatic macroinvertebrate community and physical habitat data from the aquatic macroinvertebrate monitoring site on Bright Angel Creek in Grand Canyon National Park, Arizona, 2009–2012

Table G1. Quantitative aquatic macroinvertebrate community metrics from BRI01 on Bright Angel Creek in Grand Canyon NP. For a given order, tolerance or functional feeding group, abundance-based metrics are expressed as the percentage of individuals in the group, while richness-based metrics for all years are expressed as the percentage of taxa in the group.

	2010 (*n* = 5)		2011 (*n* = 5)		2012 (*n* = 5)	
Quantitative metric	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Total abundance	672.20	69.16	340.80	219.59	738.40	100.42
Total richness	18.60	3.85	17.40	2.30	17.60	2.30
Simpson's Diversity—taxonomic	0.78	0.06	0.79	0.05	0.80	0.03
Simpson's Diversity—functional group	0.50	0.16	0.36	0.06	0.37	0.10
Dominant taxa	35.42	4.60	35.96	6.41	33.96	5.52
Tolerance group						
Relative abundance of tolerant taxa (%)	0.31	0.35	0.88	1.01	0.22	0.22
Relative abundance of moderately tolerant taxa (%)	28.32	13.16	74.73	9.23	47.36	10.16
Relative abundance of intolerant taxa (%)	71.37	13.07	24.69	9.01	52.42	10.19
Richness of tolerant taxa (%)	4.11	3.99	7.58	4.71	5.35	5.22
Richness of moderately tolerant taxa (%)	43.71	3.14	41.58	2.78	46.15	9.26
Richness of intolerant taxa (%)	52.18	4.99	50.85	2.78	48.50	5.66
Functional group						
Relative abundance of collector-filterers (%)	13.11	6.59	15.76	5.11	15.24	14.04
Relative abundance of collector-gatherers (%)	59.39	19.76	77.82	4.78	75.95	12.14
Relative abundance of scrapers (%)	24.91	20.68	2.07	1.90	5.40	1.00
Relative abundance of shredders (%)	0.00	0.00	0.04	0.09	0.06	0.14
Relative abundance of predators (%)	2.59	1.54	4.30	1.91	3.34	1.34
Richness of collector-filterers (%)	17.69	3.57	19.05	2.73	17.46	2.34
Richness of collector-gatherers (%)	36.51	1.12	38.72	5.71	35.16	5.95
Richness of scrapers (%)	20.01	5.30	11.08	4.76	16.48	5.89
Richness of shredders (%)	0.00	0.00	1.05	2.35	1.43	3.19
Richness of predators (%)	25.79	7.21	30.09	3.79	29.47	4.70
Taxonomic group						
Number of EPT taxa	7.40	0.89	6.80	1.48	7.00	0.71
Relative abundance of EPT taxa (%)	51.99	12.34	49.57	5.78	48.41	8.45
Relative abundance of Ephemeroptera (%)	35.93	13.04	42.28	3.99	41.96	10.30
Relative abundance of Plecoptera (%)	0.00	0.00	0.08	0.19	0.00	0.00
Relative abundanceof Trichoptera (%)	16.06	8.74	7.21	3.05	6.45	2.34
Relative abundance of noninsect taxa (%)	2.86	1.86	7.09	4.20	9.36	3.66
Relative abundance of Chironomidae Diptera (%)	11.25	7.04	24.39	8.20	7.72	2.23
Relative abundance of non-Chironomidae Diptera (%)	21.59	17.72	10.47	3.08	9.98	12.39
Relative abundance of Coleoptera (%)	11.31	9.56	8.21	3.78	24.37	8.75
Relative abundance of Odonata (%)	0.99	0.78	0.27	0.31	0.15	0.13

Table G2. Qualitative aquatic macroinvertebrate community metrics from BRI01 on Bright Angel Creek in Grand Canyon NP. Richness-based metrics are expressed as the percentage of taxa in a given order, tolerance or functional feeding group.

Qualitative metric	2010	2011	2012
Taxa richness	26	22	25
Tolerance group			
Richness of tolerant taxa (%)	8.33	9.52	13.04
Richness of moderately tolerant taxa (%)	45.83	33.33	43.48
Richness of intolerant taxa (%)	45.83	57.14	43.48
Functional group			
Richness of collector-filterers (%)	11.54	15.00	16.00
Richness of collector-gatherers (%)	34.62	35.00	36.00
Richness of scrapers (%)	11.54	15.00	12.00
Richness of shredders (%)	0.00	10.00	0.00
Richness of predators (%)	42.31	25.00	36.00
Taxonomic group			
Number of EPT taxa	8	8	9
Richness of EPT taxa (%)	30.77	36.36	36.00
Richness of Ephemeroptera (%)	15.38	13.64	16.00
Richness of Plecoptera (%)	0.00	0.00	0.00
Richness of Trichoptera (%)	15.38	22.73	20.00
Richness of noninsect taxa (%)	19.23	13.62	24.00
Richness of Chironomidae Diptera (%)	11.54	13.64	12.00
Richness of non-Chironomidae Diptera (%)	19.23	27.27	16.00
Richness of Coleoptera (%)	7.69	4.55	4.00
Richness of Odonata (%)	11.54	4.55	8.00

Table G3. Physical habitat and hydrologic data from BRI01 on Bright Angel Creek in Grand Canyon NP, Arizona, 2009–2012. Particle embeddedness and canopy closure measurements are expressed as percentages.

	2010		2011		2012	
Physical habitat metric	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Microhabitat level (*n* = 5)						
Riffles						
Velocity (m/s)	0.56	0.26	0.75	0.31	0.68	0.30
Depth (m)	0.15	0.07	0.24	0.06	0.20	0.04
Embeddedness (%)	23.6	15.3	30.8	14.0	48.0	11.9
Transect level (*n* = 11)						
Channel dimensions						
Velocity (m/s)	0.42	0.18	0.50	0.18	0.54	0.21
Depth (m)	0.20	0.06	0.25	0.09	0.19	0.11
Wetted channel width (m)	6.9	2.5	5.9	1.7	5.9	2.0
Active channel width (m)	17.6	5.0	17.7	5.7	15.1	3.6
Riparian cover						
Canopy closure (%)	12.4	24.2	2.1	7.7	2.8	15.8
Reach level (*n* = 1)						
Water quality	**Value**		**Value**		**Value**	
Temperature (°C)	13.8		13.3		14.4	
Specific conductivity (µS/cm)	352		343		335	
pH	8.6		8.8		8.8	
Dissolved oxygen (% saturation)	100.5		99.7		102.1	
Dissolved oxygen (mg/L)	9.4		9.4		8.6	
Turbidity (NTU)	0.60		2.7		1.7	
Discharge (cfs)	21.3		21.7		19.8	

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