Barton and related springs benthic macroinvertebrate community assessment

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Abstract

Benthic macroinvertebrate community assessments were conducted in Barton Springs Pool (Parthenia), Eliza, Old Mill(Sunken Garden/Zenobia) and Upper Barton Springs in Austin, Texas. These springs are the only known habitat of the endangered Barton Springs Salamander, Eurycea sosorum and the Austin Blind Salamander, E. waterlooensis. The presumed preferred prey of these salamanders, Chironomidae, Ostracoda, Amphipoda, (USFWS 2004) were observed. Procambarus clarkii and several Argia sp. are potential predators of the salamanders,and were also observed at all sites. Both prey and predator species abundances significantly positively correlated with Barton Springs mean daily discharge when data from all sites are combined. Diversity and abundance of macroinvertebrates generally decreased from 2005 to 2006, corresponding to decreases in Barton Springs discharge.

Introduction

Water quality is frequently evaluated using chemical data or physical measurements of habitat. These measurements provide useful information on the environmental setting, but can fail to evaluate the biological health or integrity of aquatic ecosystems. A direct measure of the ecological suitability of aquatic habitats can be obtained by sampling varied forms of aquatic invertebrates found in and on the substrate. Diversity and abundance of indicator species of aquatic macroinvertebrates are commonly used in biotic indices of stream pollution and ecosystem condition (Spellman and Drinan 2001).

The Contributing and Recharge zones of the Barton Springs Complex are undergoing rapid human population growth, which may promote degradation of water quality in surface creeks. Since creek flows contribute the majority of recharge water to the aquifer, this can result in declining water quality and degradation of habitat in the spring outflows. Since this spring complex is the only known habitat of the endangered Barton Springs Salamander, *Eurycea sosorum*, and the candidate Austin Blind Salamander, *E. waterlooensis*, it is imperative that these changes are well documented and potential effects on these species evaluated. Both species are known to prey on benthic invertebrates (Chippindale et al. 1993, Hillis et al. 2001), and gut analyses of wild *Eurycea sosorum* have shown their most common prey to be members of the groups Chironomidae, Amphipodidae and Ostracoda (USFWS 2004, Hernandez 1997). Likewise, some invertebrates, such as large Odonates, may prey on salamander eggs or juveniles (USFWS 2004). This study examined the benthic invertebrate community living in salamander habitat in

Barton (Parthenia), Eliza, Old Mill (Sunken Garden/Zenobia), and Upper Barton Springs, as well as surrounding habitat in Barton Springs Pool. This assessment of the benthic community will provide a baseline with which future conditions can be compared. It will also be useful in quantitatively investigating its relationship with salamander abundance and physicochemical characteristics of habitat. Monitoring protocols for the invertebrate community in deep pools is under development by TCEQ (Jack Davis 1999).

The purpose of this study is to:

- Develop an appropriate biological reference condition for these particular spring habitats to gauge the extent of future degradation and assess progress in habitat restoration projects.
- Provide site-specific baseline data for inferring potential stressors and their effects on the habitats at these springs. Stressors include fluctuations in biological community composition, predator and prey species abundance.
- Evaluate biological integrity of the springs exposed to various levels of habitat alteration. Data could be used to develop site-specific diagnostic indicators and monitoring strategies for guiding the identification of springs with degraded ecosystems and tracking changes temporally under different management practices.(For example, Barton Springs is open to public with restrictions, Eliza and Sunken Gardens are closed to the public and Upper Barton Springs is open to the public with no restrictions.)
- Provide a current inventory of macroinvertebrate communities inhabiting these springs to facilitate:
    - a quantitative and dated inventory of the benthic macroinvertebrate species of the springs
    - determination of potential prey species for the Barton Springs Salamander
    - correlation of these prey species to salamander abundance
    - trend analysis to determine health of the system,
    - identification of what type of habitat restoration/supplementation may be required.

Table 1. Study sites.

Site #	Site Name
35	Barton Spring (Parthenia – Main spring outlet)
2514	Barton Springs Pool @ Shallow End
2515	Barton Springs Pool @ Beach Area
2516	Barton Springs Pool @ Deep End
183	Upper Barton Spring
428	Eliza Spring
422	Old Mill (Sunken Garden/ Zenobia) Spring
3594	Old Mill Stream (outflow from spring pool)

Figure 1. Map of study sites near Barton Springs Pool, Austin, Texas.

Barton Springs Pool is a large impounded system; Parthenia Spring feeds Barton Springs Pool, which is dammed upstream and downstream. The Pool is used recreationally by citizens and tourists. Average combined discharge from spring outflows is 32 mgd (49.5 ft^3/s), although discharges as high as 90 mgd (166 ft^3/s) and as low as 14 mgd (9.6 ft^3/s) have been recorded. The water depth in Barton Springs Pool ranges from 0.5 – 20.0 feet. The substrate where Main Spring discharges consists of bedrock with fissures, and areas of boulder, cobble and gravel. The areas immediately adjacent to the outflows lack sediment, however, much of the remaining area is covered with a layer of sediment that ranges in thickness from 0.5 – 6 inches (COA biologists- unpublished data). The fissures contain clumps of the moss, *Amblystegium riparum*, and substrate nearest outflows are inhabited by various green and red algae. The Pool also contains an artificially reconstructed area of habitat on the north side, referred to as gravel beach. The substrate here consists of a contoured gravel and cobble beach, which is covered with sediment from 0.25- 3 inches deep, and includes stands of the macrophyte, *Sagittaria graminea.*

Eliza and Sunken Garden Springs are enclosed by manmade structures that form impounded areas of similar size and depth with spring influents upwelling from the bottom of the structures.
Eliza is a large (approximately 45' by 60') oval shaped cement structure which has five sets of benches encircling an impounded center. The substrate in Eliza Spring consists of flat concrete with seven circular openings for the spring influent from beneath the concrete. Spring influent is also emitted from fifteen rectangular vents at regular intervals along the bottom of the riser to the first bench. The effluent from this spring exits through an opening in the southeast edge of the impounded area, and flows through a buried

concrete culvert into the Barton Springs Pool Bypass tunnel and out into lower Barton Creek. At this time (July 2003), the water depth of the ponded area is between 1.5-2.0 feet.

Old Mill/ Sunken Gardens Spring is an area impounded by a circular rock structure (approximate radius = 21 feet) built to enclose the spring. The substrate remains in a natural state. Large boulders, cobble, sand, marl and sediment have accumulated to form a substrate that varies in both composition and depths. At the initiation of this study (July 2003), the water depth was about 6-7 feet in the center and about 4.5 - 5 feet around the edges. The outfall of this structure is built into the north wall approximately five feet above the substrate. A culvert flows directly into Barton Creek and is feed by seepage from beneath the walls. A separate surface stream receives outflow from the north wall and also ultimately drains into Barton Creek.

These two springs are similar in size, flow regimes and water depths; both also have spring upwellings within the substrate, leading to relatively tranquil water conditions within the spring pools. Neither Eliza nor Sunken Garden have additional inflows from other sources, except during storm events when Eliza can have sheet flow influent from Zilker Park.

Upper Barton Spring is located on the south bank of Barton Creek approximately 1/8 mile upstream of Barton Springs Pool. This spring has been left in a natural state, with a large percentage of the immediate habitat consisting of riffles flowing from the spring area into Barton Creek. Discharge rates vary considerably at this spring from 0 to about 2 cfs. When Barton Springs discharge drops below 40 cfs, the entire surface of the spring area is dry. In addition, this site is inundated with flow from Barton Creek during periods of high flow and heavy rainfall. The pooled spring area was approximately 10' x 17' at the time of this study (July 2003). The riffle areas consist of shallow cobble filled runs. The water depth is relatively shallow compared to the other 3 springs in the area, with depths ranging from 2.5 feet at the discharge point of the spring, to about 6 inches, with 6 inches being the average depth in the riffle areas.

Methods

This study replicated and expanded on an initial study completed in August 2000. Six sites in Barton Springs Pool were sampled for macroinvertebrates with a dip net in August 2000. Dip net (1.4' x0.7', mesh size 500 microns) and d-net (1.0' x .5', mesh size 500 microns) samples were used to collect benthic macroinvertebrates from all habitats of Barton Springs Pool (beach, planted area, deep, fissures and shallow area), Eliza, Old Mill, and its outflow stream and Upper Barton Spring in Spring and Summer of 2005 and 2006. Surber (1.0' x 1.0', mesh size 600 microns) sampling was used to sample the riffle of Upper Barton Spring and the outflow riffle of Old Mill Spring in addition to dip nets. Organisms were collected from nets in the field, preserved in 100% reagent alcohol and returned to ERM lab for analysis. Additional sites in deeper areas of the Barton Springs Pool, Eliza and Old Mill Springs were sampled with Hester-Dendy (10 sets of 9- 0.2" x0.2" plates) samplers in 2004 and are included in this assessment.

Differences among sites were assessed by the non-parametric Kruskal-Wallis test over the period of record, with differences among locations within a single site explored using the Ryan-Einot-Gabriel-Welsch multiple range test specified in SAS (version 9.1).

Additional benthic macroinvertebrate observations generated from non-quantitative sampling methods are included as an appendix.

Twenty two benthic macroinvertebrate metrics (see Table 4) were used to compare among and within sites, including Barton Creek immediately upstream of Barton Springs Pool, during the study period 2005-2006. Metrics were calculated based on TCEQ Surface Water Quality Procedure Manual methods

(TCEQ 2007) and consistent with COA WRE standard procedures. These metrics include measures based on diversity, pollution tolerance and abundance.

The probability of occurrence for taxa encountered at every site, including some of the potential predator and prey species, was also used to assess differences between sites. The probability of occurrence was calculated as the number of days a taxon was found divided by the total number of sample days at a site sites

Results

Detailed dated inventories of benthic macroinvertebrates encountered during this study are available by request from the City of Austin Field Sampling Database (insert web link). Based on the entire period of record (2000-2006), 81 unique benthic macroinvertebrate taxa were identified. Ten taxa appear ubiquitous and were observed at all springs (Table 2). More unique taxa were observed only in Barton Springs Pool than any other spring site, although a larger number of locations were sampled within Barton Springs Pool than any other site. Eliza and Old Mill Springs yielded the smallest number of unique taxa and the smallest total number of taxa (Table 3).

Of the 24 taxa observed in Old Mill Spring, only 3 taxa (*Hyalella azteca*, Orthocladiinae, *Psephenus* sp.) were observed in both the spring and stream locations (422 and 3594, respectively) sampling locations. Of the 55 taxa observed within Barton Springs Pool, only 4 (*Dugesia tigrina*, Orthocladiinae, *Callibaetis sp*, Hydracarina) were observed at all four sampling locations. Only 5 total taxa were observed at the shallow end of the pool (location 2514), less than at any other spring site, and no taxon observed at the shallow end was unique to that location. More unique taxa were observed at the main outlet of Parthenia Spring (location 35) than any other location within Barton Springs Pool.

The predominant prey of the Barton Springs Salamander, chironomids, ostracods, and amphipods, (Chippindale et al. 1993, Hillis et al. 2001, COA unpublished) are generally observed at all sites, although ostracods have not been observed at Eliza Spring in quantitative sampling (2000-2006). One other possible prey species observed at all sites include the Ephemeropteran, *Stenonema sp*. *Procambarus clarkii* and several *Argia sp.* are potential predators of these salamanders, and were also observed at all sites. Although the flatworms, *Dugesia tigrina,* were observed at all sites, it is not known whether this species is predator or prey for *E. sosorum*, The *Psephenus sp,*, observed at all sites, is not presumed to be either predator or prey.

Table 2. Taxa common and unique to spring sites with all locations within Barton Springs Pool and Old Mill Spring combined.

All sites	Barton	Upper Barton	Eliza	Old Mill
Argia sp.	*Berosus sp*	*Aquarius sp*	*Ephydridae*	*Baetodes sp*
Chironominae	*Brachycercus sp*	*Baetidae*	*Helphorus sp*	*Pleurocera sp*
Dugesia tigrina	*Chironomidae*	*Brechmorhoga mendax*	*Hemerodromia sp*	*Stygobromus sp*
Hyalella azteca	*C. cincinnatiensis*	*Camelobaetidius sp*	*Macrovelia sp*	
Oligochaeta	*Curculionidae*	*Chimarra sp*	*Salda sp*	
Orthocladiinae	*Dubiraphia sp*	*Dytiscidae*		
Procambarus clarkii	*Dythemis fugax*	*Ephydra sp*		
Psephenus texana	*Elimia sp*	*Heterelmis sp*		
Stenonema sp	*Helichus sp*	*Hexatoma sp*		
Tanypodinae	*Helobdella sp*	*Macromia sp*		
	Hexagenia sp	*Microvelia sp*		
	Hydrobiidae	*Nematomorpha*		
	Hydrobiomorpha sp	*Perlesta sp*		
	Hydrophilidae	*Rhagovelia sp*		
	Hydroporus sp	*Stenelmis sp*		
	Nectopsyche sp			
	Pelocoris sp			
	Peltodytes sp			
	Polycentropus sp			
	S. bartonensis			
	Tanytarsini			
	Trichocorixa sp			
	V. packeri			

Table 3. Summary of total number of taxa found by site.

Site	Total # Taxa
Old Mill Spring (all)	**24**
Spring Pool	*13*
Stream	*14*
Barton Springs (all)	**55**
Spring outlet	*38*
Shallow end	*5*
Beach area	*38*
Deep end	*28*
Eliza Spring	**25**
Upper Barton Spring	**44**

The number of taxa found using each sampling method (kick net/surber versus Hester-Dendy sampler) were compared. More taxa were encountered using nets and surbers than Hester-Dendy samplers. Only Hydrophilidae was encountered in Hester-Dendy samplers and not by kick net or surber sampling.

Of the 15 unique taxa observed at Upper Barton Spring, 7 were observed only during the 2002 sampling event and not observed in 2005. Upper Barton Springs was dry in 2006 and therefore, no samples were collected. Only 5 taxa (*Helichus* sp., Curculionidae*, Hydrobiomorpha* sp*., Pelocoris* sp., *Peltodytes* sp.) were observed only within Barton Springs Pool in the initial sampling years (2000-2004), but not observed during the subsequent sampling (2005-2006).. At least 37 different taxa were observed during the 2005-2006 study period that had not been observed previously by quantitative sampling methods (2000-2004).

Two metrics, “percent of total as elmidae” and “percent of trichoptera as hydropsychidae,” were not useful in differentiating sites as elmidae and hydropsychidae were infrequently or never encountered.

Data were used to assign a qualitative aquatic life use scores to each site according to the Texas Commission on Environmental Quality standards (TCEQ 2007). Each perennial spring site were categorized as “limited”, except Upper Barton Spring, which yielded an “intermediate” score. In general, surface water locations in Onion and Barton Creeks have scored in the “high” category . Barton Creek immediately upstream of Barton Springs Pool yielded an average score of “high” for the 2005-2006 study period.

Of 22 metrics assessed by Kruskal-Wallis test (Table 4) fourteen metrics indicate statistically significant differences among sites ($p \leq 0.05$). An additional 5 metrics indicate marginally significantly differences among spring sites ($p \leq 0.10$) but with lower statistical confidence. Upper Barton Spring yielded better metric values (less impaired) than other sites for 16 of the 22 metrics. The large number of organisms at Eliza Spring was the result of the collection of more than 5,000 *Hyalella azteca* during the March 2005 survey. Highlighted metrics in Table 4 indicate higher diversity and less impairment in Upper Barton Spring according to the multimetric approach to analyses. This site resembles a surface water riffle and TCEQ metrics were developed for this type of habitat.

Table 4. Site group means (2000-2006) by metric with Kruskal-Wallis Test probability > χ^2.

Metrics	BS	ES	OMS	UB	*Pr>* χ^2
EPT/EPT+CHIRONOMIDAE	0.199	0.231	0.582	0.370	*0.2168*
HILSENHOFF BIOTIC INDEX	6.586	7.851	7.200	5.670	*0.0170*
NUMBER OF DIPTERA TAXA	2.278	1.571	0.500	5.000	*0.0047*
NUMBER OF EPHEMEROPTERA TAXA	1.333	0.143	0.750	2.333	*0.0259*
NUMBER OF EPT TAXA	1.722	1.000	1.250	5.333	*0.0929*
NUMBER OF INTOLERANT TAXA	2.333	1.143	2.125	5.667	*0.0919*
NUMBER OF NONINSECT TAXA	5.611	4.000	2.375	7.000	*0.0245*
NUMBER OF ORGANISMS	385.833	2327.571	828.125	300.667	*0.0015*
NUMBER OF TAXON	11.056	8.143	5.250	24.000	*0.0092*
PERCENT DOMINANCE (TOP 1 TAXA)	48.338	35.379	77.138	17.840	*0.0072*
PERCENT DOMINANCE (TOP 3 TAXA)	72.782	39.513	85.477	34.617	*0.0020*
PERCENT OF TOTAL AS CHIRONOMIDAE	35.134	1.314	0.201	23.927	*0.0001*
PERCENT OF TOTAL AS COLLECTOR/GATHERER	48.444	94.510	81.534	11.563	*0.0002*
PERCENT OF TOTAL AS DOMINANT GUILD (FFG)	68.576	94.510	87.405	53.967	*0.0013*
PERCENT OF TOTAL AS ELMIDAE	0.079	0.004	0.130	0.167	*0.8254*
PERCENT OF TOTAL AS EPT	8.826	0.219	7.963	12.547	*0.0573*
PERCENT OF TOTAL AS FILTERERS	32.011	1.750	0.460	26.037	*0.0004*
PERCENT OF TOTAL AS GRAZERS (PI AND SC)	7.705	1.999	15.715	39.820	*0.0884*
PERCENT OF TOTAL AS PREDATOR	22.082	4.684	1.236	23.063	*0.0020*
PERCENT OF TOTAL AS TOLERANT ORGANISMS	5.604	0.107	0.466	0.507	*0.0792*
PERCENT OF TRICHOPTERA AS HYDROPSYCHIDAE	0.000	0.000	0.000	0.000	*1.0000*
RATIO OF INTOLERANT TO TOLERANT ORGANISMS	0.512	0.023	0.501	0.877	*0.0739*
TCEQ QUALITATIVE AQUATIC LIFE USE SCORE	18.778	17.571	15.250	26.667	*0.0102*

BS=Barton Springs (all locations)
ES=Eliza Springs
OM=Old Mill Spring (all locations)
UB=Upper Barton

Differences in the invertebrate community between Upper Barton Spring and the other sites may be a result of ephemeral surface water and its similarities to a surface water habitat. To gain a better understanding of invertebrate community variation among the perennial spring sites, Upper Barton Spring data were excluded and Kruskal-Wallis tests of all metrics were conducted. Of the 22 metrics, 14 yielded significant differences between Barton, Eliza and Old Mill Springs. Old Mill and Eliza Springs yielded higher percent dominant guild values, and Barton Springs appears to contain more taxa sensitive to water quality degradation and a more balanced and diverse community structure.

Metric values for sampling locations within Barton Springs Pool were not significantly different for 20 metrics ($p \geq 0.05$, Table x). However, there were significantly more grazer individuals as a percent of total at the beach area of the Pool, and lower percent Chironomidae and EPT/EPT+Chironomidae at the deep end of the Pool.

Table 5. Location means (2000-2006) for Barton Springs Pool by metric with Kruskal-Wallis Test probability > χ^2.

parameter	BS	BSS	BSB	BSD	***Pr*> χ^2**
EPT/EPT+CHIRONOMIDAE	0.121	0.119	0.044	0.479	*0.0674*
HILSENHOFF BIOTIC INDEX	6.361	5.730	6.668	6.988	*0.4703*
NUMBER OF DIPTERA TAXA	2.429	1.000	2.800	1.800	*0.7310*
NUMBER OF EPHEMEROPTERA TAXA	1.000	1.000	1.800	1.400	*0.9451*
NUMBER OF EPT TAXA	1.286	1.000	2.600	1.600	*0.9761*
NUMBER OF INTOLERANT TAXA	2.143	2.000	3.000	2.000	*0.8361*
NUMBER OF NONINSECT TAXA	4.429	3.000	7.800	5.600	*0.5568*
NUMBER OF ORGANISMS	336.714	68.000	605.800	298.200	*0.5171*
NUMBER OF TAXON	9.857	5.000	15.200	9.800	*0.4135*
PERCENT DOMINANCE (TOP 1 TAXA)	41.839	76.470	37.132	63.018	*0.1388*
PERCENT DOMINANCE (TOP 3 TAXA)	66.530	92.640	64.554	85.792	*0.5012*
PERCENT OF TOTAL AS CHIRONOMIDAE	51.520	76.470	24.538	14.522	*0.0774*
PERCENT OF TOTAL AS COLLECTOR/GATHERER	32.956	10.290	48.386	77.818	*0.0348*
PERCENT OF TOTAL AS DOMINANT GUILD (FFG)	69.339	76.470	54.898	79.608	*0.1841*
PERCENT OF TOTAL AS ELMIDAE	0.086	0.000	0.000	0.164	*0.3944*
PERCENT OF TOTAL AS EPT	6.746	10.290	1.438	18.834	*0.2450*
PERCENT OF TOTAL AS FILTERERS	52.713	76.470	22.308	3.840	*0.0167*
PERCENT OF TOTAL AS GRAZERS (PI AND SC)	3.604	0.000	20.190	2.502	*0.0752*
PERCENT OF TOTAL AS PREDATOR	29.401	10.290	18.012	18.264	*0.9147*
PERCENT OF TOTAL AS TOLERANT ORGANISMS	1.669	0.000	6.888	10.950	*0.3808*
PERCENT OF TRICHOPTERA AS HYDROPSYCHIDAE	0.000	0.000	0.000	0.000	*1.0000*
RATIO OF INTOLERANT TO TOLERANT ORGANISMS	0.153	0.150	0.304	1.294	*0.8560*
TCEQ QUALITATIVE AQUATIC LIFE USE SCORE	17.571	19.000	20.200	19.000	*0.7734*
TCEQ QUANTITATIVE AQUATIC LIFE USE SCORE	19.857	15.000	22.600	19.400	*0.3616*

BS = main spring outlet
BSS = shallow end of pool
BSD = deep end of pool
BSB = beach area

The invertebrates from Old Mill Spring pool and the outflow stream were significantly different according to 6 of the metrics (Table 6). Fewer taxa and more collector/gatherers were found in the Old Mill Spring pool, while more grazers and EPT taxa were found in Old Mill stream. There were no significant differences in any richness metric.

Table 6. Location means (2000-2006) for Old Mill by metric with Kruskal-Wallis Test probability > χ^2.

parameter	OM	OMS	**Pr> χ^2**
EPT/EPT+CHIRONOMIDAE	0.533	0.662	1.0000
HILSENHOFF BIOTIC INDEX	7.896	6.040	0.0512
NUMBER OF DIPTERA TAXA	0.400	0.667	0.8633
NUMBER OF EPHEMEROPTERA TAXA	0.800	0.667	0.6933
NUMBER OF EPT TAXA	0.800	2.000	0.3340
NUMBER OF INTOLERANT TAXA	1.200	3.667	0.1665
NUMBER OF NONINSECT TAXA	2.400	2.333	1.0000
NUMBER OF ORGANISMS	805.000	866.667	0.8815
NUMBER OF TAXON	4.000	7.333	0.2938
PERCENT DOMINANCE (TOP 1 TAXA)	94.844	47.627	0.1011
PERCENT DOMINANCE (TOP 3 TAXA)	98.948	67.517	0.3725
PERCENT OF TOTAL AS CHIRONOMIDAE	0.264	0.097	0.8644
PERCENT OF TOTAL AS COLLECTOR/GATHERER	98.290	53.607	0.0526
PERCENT OF TOTAL AS DOMINANT GUILD (FFG)	98.290	69.263	0.0526
PERCENT OF TOTAL AS ELMIDAE	0.000	0.347	0.0510
PERCENT OF TOTAL AS EPT	1.626	18.523	0.3682
PERCENT OF TOTAL AS FILTERERS	0.634	0.170	0.6084
PERCENT OF TOTAL AS GRAZERS (PI AND SC)	1.586	39.263	0.0471
PERCENT OF TOTAL AS PREDATOR	1.318	1.100	0.6468
PERCENT OF TOTAL AS TOLERANT ORGANISMS	0.746	0.000	0.2416
PERCENT OF TRICHOPTERA AS HYDROPSYCHIDAE	0.000	0.000	1.0000
RATIO OF INTOLERANT TO TOLERANT ORGANISMS	0.020	1.303	0.0389
TCEQ QUALITATIVE AQUATIC LIFE USE SCORE	14.200	17.000	0.6426

. The probabilities of occurence of *Hyalella azteca* in any of the spring sites and locations are very high ($p \geq 0.80$) except in the shallow end of Barton Springs Pool ($p = 0.0$) (Table 7). This is most likely due to a lack of suitable habitat. The potential predator, *Procambarus clarkii*, is more likely to be encountered in Barton Springs Pool than in the other spring sites, although *Argia* sp. are more likely to be encountered at Eliza and Upper Barton Springs than at Barton Springs pool. The smaller trichopterans (possible prey for salamanders) ,*Hydroptila sp.* were observed at all sites, but others, such as *Leucotrichia sarita* and *Metrichia sp.,* were observed only at Eliza, Old Mill stream and Upper Barton Springs.

Table 7. Probability of occurrence for select taxa by site.

Taxa	BS	BSS	BSB	BSD	ES	OM	OMS	UBS
Argia	0.00	0.00	0.00	0.20	0.29	0.00	0.33	1.00
Chironominae	1.00	0.00	1.00	0.60	0.71	0.20	0.00	1.00
Dugesia tigrina	0.29	1.00	0.40	0.20	1.00	0.00	0.67	1.00
Hyalella azteca	1.00	0.00	1.00	0.80	1.00	1.00	1.00	1.00
Oligochaeta	0.29	0.00	0.80	0.80	0.71	0.60	0.00	0.67
Orthocladiinae	0.71	1.00	0.80	0.20	0.71	0.20	0.33	0.67
Procambarus	0.43	0.00	0.40	0.20	0.14	0.40	0.00	0.33
Psephenus	0.43	0.00	0.60	0.00	0.57	0.20	1.00	1.00
Stenonema	0.29	0.00	0.40	0.40	0.14	0.20	0.00	0.67
Tanypodinae	0.57	0.00	0.60	0.40	0.29	0.20	0.00	0.33

BS = Barton Springs main outlet
BSS = Barton Springs shallow end
BSB = Barton Springs beach area
BSD = Barton Springs deep end
ES = Eliza Springs
OM = Old Mill Springs
OMS = Old Mill outfall stream
UBS = Upper Barton Springs

Based on Spearman Ranked Data correlation test on taxa occurring at Old Mill, Barton and Eliza Springs combined, only *Hyalella azteca* , Orthocladiinae, and *Psephenus*. abundances are significantly and positively correlated with Barton Springs mean daily discharge. *Dugesia tigrina* are inversely related to discharge although the correlation is not significant. Mean daily dissolved oxygen concentrations changed from 6.94 mg/L on 11 March 2005 during high discharge conditions to 5.04 mg/L on 10 March 2006 during the lower discharge conditions based on USGS datasondes continuously deployed at the springs. The small number of sample points irregularly spaced across widely variable Barton Springs discharge complicates the analysis (Figure 2).

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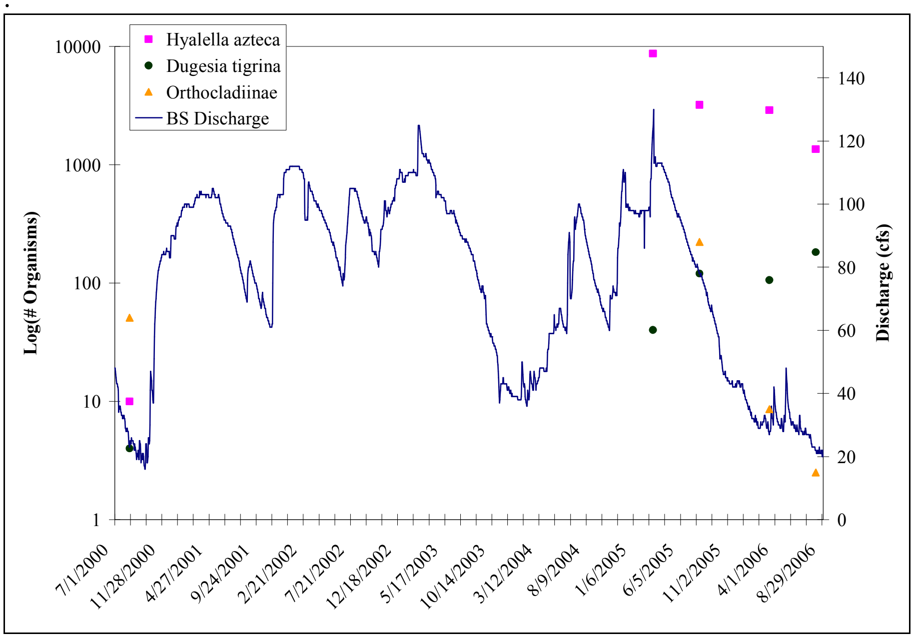

Figure 2. Barton Springs mean daily discharge with total number of *Hyalella azteca*, *Dugesia tigrina*, and Orthocladiinae summed for all sites. Note the logarithmic scale.

The abundance of the Barton Springs Salamander and dissolved oxygen concentration in Barton Springs Pool are related to Barton Springs discharge (COA 2004). Lagging increases in salamander abundance were observed in Barton Springs Pool only during periods of flow recession up to a limiting flow condition, presumably when dissolved oxygen deficits may adversely affect salamanders. During the 2005-2006 study period, salamander counts appear to follow the expected pattern in both Barton Springs Pool and Eliza Spring until the spring of 2006 when salamander abundance begins to decline (Figure 3). Analyses show *Hyalella azteca* numbers not correlating with salamander abundance at Old Mill Spring.

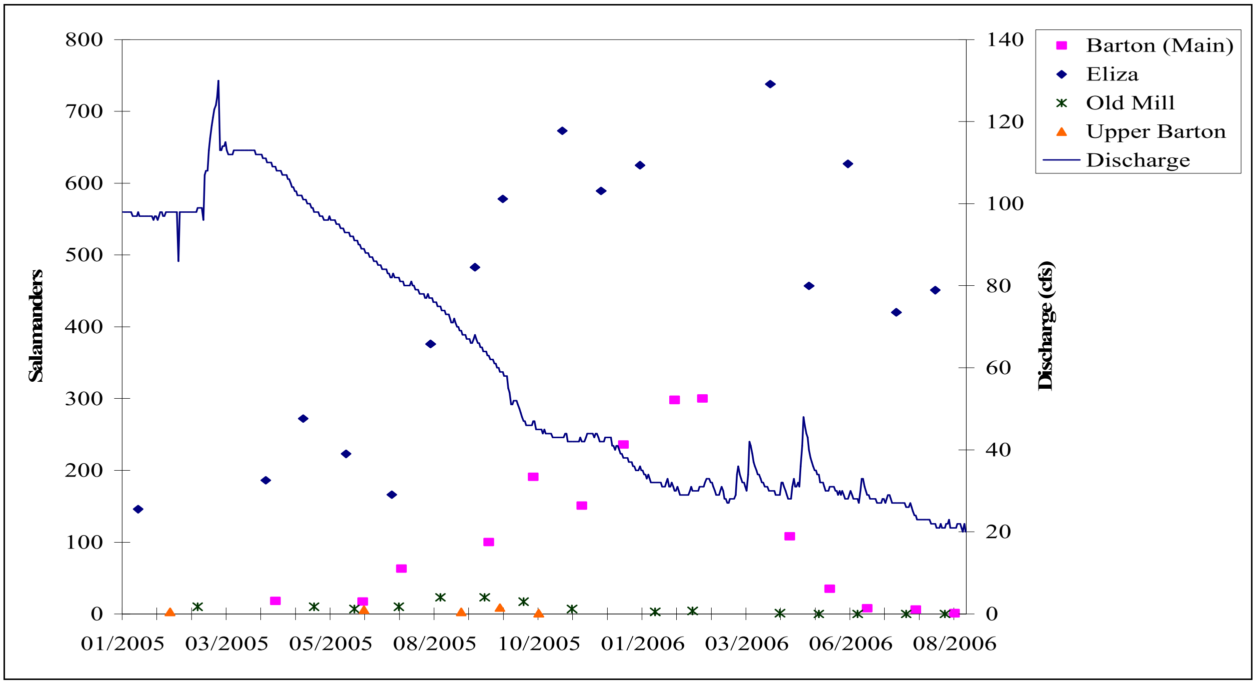

Figure 3. Barton Springs total salamander counts by site versus mean daily Barton Springs discharge.

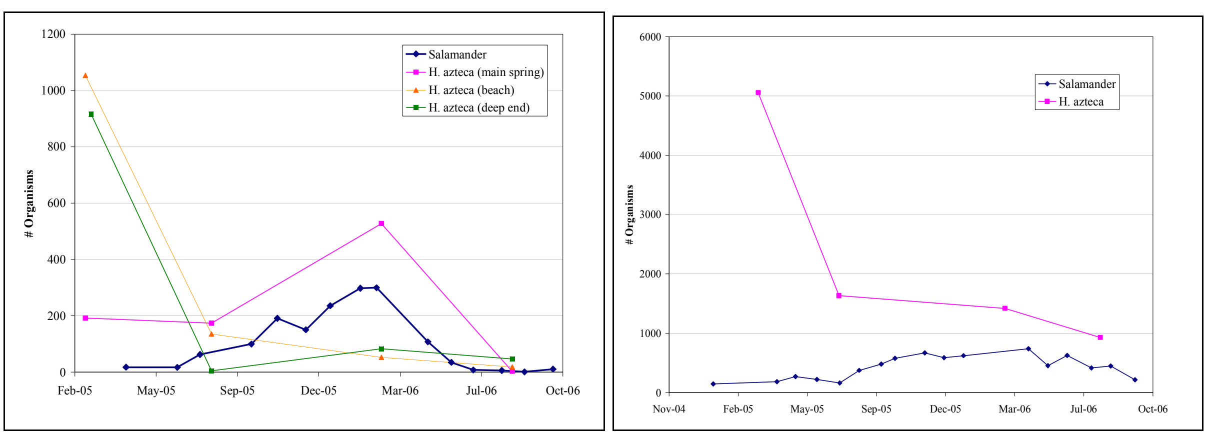

Figure 4. *Hyalella azteca* counts versus Barton Springs salamander counts at Barton Springs Pool (left) and Eliza Spring (right).

Diversity and abundance generally decreased from 2005 to 2006, corresponding to decreases in Barton Springs discharge. Upper Barton Spring was dry and therefore, not sampled in 2006. In the three perennial sites, 2.1 times more taxa were observed in 2005 (55 taxa) than in 2006 (26 taxa). Only 8 of the 26 taxa found in both 2005 and 2006 had higher abundance in 2006 (Table 4). Of the taxa that increased in 2006, two of the six were the gastropods, *Elimia* sp. and *Ferrisia* sp., and one taxon was the leech common to Barton Springs, *Helobdella* sp. Flatworm, (*D. tigrina*) and aquatic mite (*Hydracarina* sp.) abundances increased with decreasing flow in 2006. The increase from one to four individuals of the ephemeropteran, *Fallceon quilleri,* (Table 8) is not statistically significant.

Table 8. Abundance by taxon (all sites) in 2005 and 2006 for taxa observed in 2006. An additional 30 taxa were observed in 2005 but not in 2006.

Taxa	2005	2006
Callibaetis	14	1
Chironominae	330	163
Chironomus	57	36
Cincinnatia cincinnatiensis	7	1
Corixidae	1	2
Dugesia tigrina	160	288
Elimia	8	118
Fallceon quilleri	1	4
Ferrissia	17	50
Helicopsyche	50	7
Helisoma anceps	66	22
Helobdella	9	15
Hyalella azteca	12703	4284
Hydracarina (Acari)	2	131
Microcylloepus pusillus	16	1
Oligochaeta	294	134
Orthocladiinae	375	50
Ostracoda	36	6
Petrophila	4	2
Physa (Physella)	10	1
Procambarus	115	41
Psephenus	982	147
Stenonema	5	5
Tanypodinae	15	3
Tanytarsini	0	3
Tricorythodes	6	1

In all sites combined, more taxa were observed during the March surveys (56) than the August surveys (45) =. Higher abundances of 43 of the 67 total taxa were also observed during the March surveys.

Conclusions

Potential salamander prey, including Chironomidae, Amphipoda, Ostracoda (except Eliza Spring), and *Stenonema* sp., were observed at all sites. Potential salamander predators, including several *Argia* species and *Procambarus clarkii* (except Old Mill outflow), were also observed at all sites.

Based on metric scores, there is little difference between the multiple sampling locations within Barton Springs Pool. However, there are generally fewer taxa observed at the shallow end of the pool and no taxa were observed at the shallow end that were not observed at another location in the pool. More unique taxa were observed at the spring outlet than any other location in Barton Springs Pool. Although physical habitat and flows differ between Old Mill Spring and the outlet stream, there is little difference in the macroinvertebrate community metric scores. However, there are few taxa (3 of 24 total taxa, *Leucotrichia sarita* Ross, *Psephenus sp* and Orthocladiinae) that are common to both Old Mill locations. Several species(for example, *Leucotrichia sarita* Ross, *Metrichia sp*. were abundant in the high flows of the outlet stream and uncommon or absent in the pooled area of Old Mill.

TCEQ qualitative aquatic life use scores indicate that the benthic macroinvertebrate communities in Barton and adjacent Springs are not as diverse or abundant as other surface water sites in Austin. However, we question the applicability of the multi-metric approach to evaluating Barton related-spring benthic macroinvertebrate community integrity. Since multi metrics were developed for use on surface water creeks and rivers with shallow riffles, multivariate assemblage methods or presence/absence and relative abundance of indicator species analyses may be more appropriate.

Upper Barton Spring generally yielded healthier metric scores than the other spring sites during 2005. This is probably due to its proximity to Barton Creek and the resulting surface water influences. Barton Springs may contain a more balanced community structure than Old Mill or Eliza Springs. More taxa have been encountered at Barton Springs Pool than other study sites, although the diversity of habitat at the larger Barton Springs site may account for this increase.

Hyalella azteca , Orthocladiinae, and *Psephenus* sp. abundances are significantly and positively correlated with Barton Springs mean daily discharge when data from all sites are combined. Diversity also decreased from 2005 to 2006, corresponding to decreases in Barton Springs discharge (Figure 2). *Dugesia tigrina* abundance may be seasonal or inversely related to flow (Thorp et al 1991). *Hyalella azteca* and the salamander may be responding similarly to environmental conditions at the main outlet of Barton Springs. One factor that influences abundance in a wide array of aquatic salamanders is availability of prey (Pianka 1983). However, there are insufficient data from benthic macroinvertebrate sampling during 2005-2006, to fully test this relationship for the Barton Springs Salamander.

Analyses show *Hyalella azteca* abundance does not correlate with salamander abundance at Old Mill Spring. However, *Hyalella azteca* is a primary prey of *E. Sosorum*, and there is a direct connection between the species that these data cannot reject.

Hyalella azteca abundance may be inversely related to salamander abundance at Eliza Spring. There was no direct relationship between *H. azteca* and salamander abundance in all locations within Barton Springs Pool, except at the Main Spring. Although not statistically significant in these locations, presence of *H. azteca* appears to be inversely correlated to salamander abundance (Figure 3). This relationship warrants further investigation. The most suitable natural salamander habitat is found in this location (Chippindale et al. 1993, Berkhouse et al 1995, Bonnett et al 2006)) which is where spring water exits the aquifer. Although regular surveys are not conducted at other locations within Barton Springs Pool, there have been no anecdotal sightings of any aquatic *Eurycea* in these areas for the last 10 years. *Hyalella azteca* is typically in higher abundance in Eliza Spring relative to other spring sites; *its* abundance decreased as salamander abundance increased over the study period (Figure 4). Increases in salamander abundance at Eliza Spring can be partially attributed to habitat reconstruction performed during the study period. However, the effect of habitat reconstruction on salamander abundance may have been exerted indirectly through changes in the invertebrate community. Such changes could have fostered the general increase in amphipods relative to the other spring sites, followed by predator/prey interactions regulating abundances of both species.

Discussion

This monitoring protocol has attempted to assess the benthic macroinvertebrate community living in salamander habitat, and is a means to determine salamander food availability. Another benefit of benthic macroinvertebrate monitoring is its usefulness is assessing the health of these springs. Declining water quality and degradation of habitat in the springs can affect this community and therefore abundance of prey for the salamanders. Future monitoring should include, but not be limited to, similar protocols for comparison purposes. Difficulties sampling in deeper pool habitats could have skewed the results in Barton Springs Pool by not acquiring representative taxa present in these deeper pools.

Snail species were not well represented by this sampling protocol, and although not considered a major prey source for the salamander, larval and juvenile forms have been noted in gut analyses. *Elimia* sp. have been observed in large numbers in Barton Springs Pool and are certainly an important component in the ecological composition of this community. *Helisoma anceps*, and several *Physa* species are also abundant in these springs. Future sampling should include a sampling strategy to assess the snail community in these springs.

Larger Odonates were expected due to the impounded nature of Barton Springs Pool although none were collected. Either the sampling protocol was inadequate or the habitat is not supportive of these species.

Barton Spring Pool discharge decreased to a low of 19 ft^3/s during 2006, and macroinvertebrate populations decreased accordingly. Future benthic macroinvertebrate surveys should be conducted during normal flow conditions.

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Appendix 1.

Additional Benthic Macroinvertebrate Taxa Observed in Non-Quantitative Sampling In Barton And Its Related Springs 1995-2001

Biologists contributing to this list include but are not limited to:

Robert Hansen
DeeAnn Chamberlain
Nick Wiersema
Ellen Geismar

OLIGOCHAETA [BC, BSP, ES, OMS, UBS]

Dero sp.
Limodrilus sp.
Pristina sp.

NEMATODA [BC, BSP, ES, OMS, UBS]

COELENTERATA

Hydra sp. [BC, BSP, ES, OMS, UBS]

HIRUDINIA	
Helobdella elongata Castle	[BC, BSP]
Helobdella stagnalis Linneaus	[BC, BSP]
GASTROPODA	
Ancylidae	
Ferrissia fragilis Tyron	[BC, BSP]
Hydrobiidae	
Phreatodrobia nugax nugax (Pilsbry & Ferriss)	[ES]
Phreatodrobia punctata Hersler & Longley	[ES]
Stygopyrgus bartonensis Hersler & Longley*	[ES]
Lymnaeidae	
Fossaria modicella Say	[BC, BSP, UBS]
Physidae	
Physella virgata rhyssa (Pilsbry)	[BC, BSP]
Planorbidae	
Gyraulus parvus Say	[BC, BSP]
Helisoma anceps anceps (Menke)	[BC, BSP]
Planorbella tenue (Dunker)	[BC, BSP]
Pleuroceridae	
Elimia comalensis Pilsbry	[BC, BSP]
Thiaridae	
Melanoides tuberculata (Müller) **	[OMS]
PELECYPODA/BIVALVIA	
Corbiculidae	
Corbicula fluminea Müller	[BC, BSP]
HYDRACHNIDIA	
Arrenurus sp.	[BC, BSP]
Hydrachna sp.	[BC, BSP]
Lebertia sp.	[BC, BSP]
Oxus sp.	[BC, BSP]
additional genera	[BC, BSP]
AMPHIPODA	
Stygobromus flagellatus	[OMS]
Stygobromus bifurcates	[BSP]
Stygobromus (possibly russelli)	[ES]
ISOPODA	
Asellidae	
Lirceolus hardeni	[BSP] [ES} [SGS]
DECAPODA	
Cambaridae	
Procambrus clarki (Girard)	[BC, BSP, ES, SGS, UPS]
Palaemonidae	
Palaemonetes kadiakensis Rathbun	[BC, BSP]

COPEPODA	[BC, BSP, ES, SGS, UPS]
OSTRACODA	
Cyprididae	
Chlamydotheca sp.	[BC, BSP, SGS]
Cypricercus sp.	[BC, BSP, SGS]
Cypridopsidae	
Potamocypris sp.	[BC, BSP, ES?, SGS]
COLLEMBOLA	
Sminthuridae	[BC, BSP, SGS]
EPHEMEROPTERA	
Baetidae	
Apobaetis indeprensus Day	[BC, BSP]
Callibaetis californicus Banks	[BC, BSP]
Callibaetis floridanus Banks	[BC, BSP, ES, SGS]
Callibaetis pictus (Eaton)	[BC, BSP, SGS]
Procloeon viridoculare (Berner)	[BC, BSP]
Caenidae	
Brachycercus flavus Traver	[BC, BSP]
Caenis latipennis Banks	[BC, BSP]
Caenis hilaris (Say)	[BC, BSP]
Emphemeridae	
Hexagenia bilineata (Say)	[BC, BSP]
Hexagenia limbata Serville	[BC, BSP]
Heptageniidae	
Stenonema femoratum (Say)	[BC, BSP, ES, SGS, UPS]
Leptohyphidae	
Tricorythodes albilineatus Berner	[BC, BSP]
ODONATA	
Aeshnidae	
Anax junius (Drury)	[BC, BSP]
Corduliidae	
Epitheca costalis (Sélys)	[BC, BSP, OMS]
Gomphidae	
Dromogomphus spinosus Sélys	[BC, BSP]
Erpetogomphus designatus Hagen in Sélys	[BC, BSP]
Coenagrionidae	
Argia immunda (Hagen)	[BC, BSP, OMS]
Argia moesta (Hagen)	[BC, BSP]
Argia translata Hagen in Sélys	[BC, BSP, OMS]
Enallagma signatum (Hagen)	[BC, BSP]
Enallagma geminata Kellicott	[BC, BSP]
Libellulidae	
Erythemis simplicicollis (Say)	[BC, BSP, OMS]
Libellula luctousa Burmeister	[BC, BSP]
Libellula incesta Hagen	[BSP]
Pachydiplax longipennis (Burmeister)	[BC, BSP]

Orthemis ferruginea (Fabricius)	[BC, BSP]
PLECOPTERA	
Leuctridae	
Zealeuctra hitei Ricker & Ross	[BC, BSP, ES, OMS, UPS]
TRICHOPTERA	
Helicopsychidae	
Helicopsyche borealis (Hagen)	[BC, BSP, OMS, UBS]
Hydroptilidae	
Ithytrichia clavata Morton	[BC, BSP]
Leucotrichia sarita Ross ***	[OMS]
Metrichia nigritta Ross	[BC, BSP, UBS]
Oxyethira sp.	[BC, BSP]
Hydropsychidae	
Cheumatopsyche pettiti (Banks)	[BC, BSP]
Leptoceridae	
Nectopsyche gracilis (Banks)	[BC, BSP, OMS]
Oecetis avara (Banks)	[BC, BSP]
Oecetis cinerascens (Hagen)	[BC, BSP]
Oecetis inconspicua (Walker)	[BC, BSP]
Triaenodes injusta (Hagen)	[BSP]
Philopotamidae	
Chimarra aterrima Hagen	[BC, BSP]
Chimarra obscura (Walker)	[BC, BSP, OMS]
Polycentropodidae	
Cernotina calcea Ross	[BSP]
Polycentropus sp	[BC, BSP]
COLEOPTERA	
Dryopidae	
Helichus lithophilus Germer	[BC, BSP]
Dytiscidae	
Copelatus chevrolati renovatus Guignot	[BC, ES]
Heterosternuta diversicornis (Sharp)	[BC, BSP]
Laccophilus vacaensis chihuahuae Zimmerman	[BC, ES]
Liodessus obscurellus (LeConte)	[ES, OMS]
Neoclypeodytes spp.	[BSP, ES]
Neoporus dimidiatus (Gemminger & von Harold)	[BC, BSP]
Elmidae	
Hexacylloepus ferrugineus (Horn)	[BC, BSP]
Neoelmis caesa (LeConte)	[BC, BSP, OMS]
Gyrinidae	
Gyrinus sp.	[BC, BSP, ES]
Halipidae	
Haliplus deceptus Matheson	[BC, BSP, OMS]
Peltodytes festivus Wehenke	[BC, BSP, ES, OMS]
Peltodytes sexmaculatus Roberts	[BC, BSP]
Hydrophilidae	
Cymbiodyta chamberlaini Smetana	[BC, BSP]
Hydrophilus triangularis Say	[ES]

Tropisternus blatchleyi blatchleyi d'Orchymont	[BC, ES]
Tropisternus lateralis nimbatus (Say)	[ES]
Psephenidae	
Psephenus texanus Brown & Arrington	[BC, BSP, ES, OMS, UPS]
DIPTERA	
Ceratopogonidae	
Dasyhelea sp.	[BC, BSP]
Palpomyia tibialis (Meigen)	[BC, BSP]
Probezzia sp.	[BC, BSP]
Chironomidae	
Ablabesmyia sp.	[BC, BSP, ES, OMS]
Cladotanytarsus sp.	[BC, BSP, ES, OMS]
Cryptochironomus sp.	[BC, BSP, ES, OMS]
Cryptotendipes sp.	[BC, BSP, ES, OMS]
Fittkauimyia sp.	[BC, BSP, ES, OMS]
Polypedilum sp.	[BC, BSP, ES, OMS]
Tanytarsus sp.	[BC, BSP, ES, OMS]
Zavreliella sp.	[BC, BSP, ES, OMS]
additional genera	
HEMIPTERA	
Belastomatidae	
Belostoma bakeri Montandon	[BC, BSP]
Naucoridae	
Cryphocricus hungerfordi Usinger	[BC, BSP]
Pelocoris biimpressus biimpressus Montandon	[BSP]
Mesoveliidae	
Mesovelia mulsanti White	[BC, BSP, ES]
Veliidae	
Microvelia paludicola Champion	[BC, BSP, ES]
MEGALOPTERA	
Sialidae	
Sialis velata Ross	[BC, BSP]

BC = Barton Creek (below Barton Springs Pool)
BSP = Barton Springs Pool
ES = Eliza Spring
OMS = Old Mill Spring (aka Sunken Garden, Walsh, or Zenobia Spring)
UBS = Upper Barton Spring
* Endemic (monotypic genus; currently only known from phreatic waters associated with Eliza Springs, additionally no live specimens yet known, only shells collected)
** Introduced Asian or African species. (point of orgin, either Africa or SE Asia)
*** Not collected as part of this study (reported in "Texas Caddisflies", S.W. Edwards. 1973. *T. Journal of Science* 24: 491-51).