**GEOLOGICAL SURVEY OF ALABAMA**

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# WATER QUALITY AND BIOLOGICAL MONITORING IN BOBCAT AND MATTHEWS CAVES, REDSTONE ARSENAL, ALABAMA, 1990-2008

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By

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with field investigations and geochemical analyses by
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# WATER QUALITY AND BIOLOGICAL MONITORING IN BOBCAT AND MATTHEWS CAVES, REDSTONE ARSENAL, ALABAMA, 1990-2008

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## ABSTRACT

Basic water chemistry from October 2007 through September 2008 remained relatively unchanged in Bobcat Cave compared to previous years. Concentrations of chloride and sulfate, parameters typically associated with increased urbanization in a watershed, remained elevated since 2006 in Bobcat and Matthews Caves. The maximum concentrations of cadmium and lead were elevated this year with a cadmium spike in Matthews Cave and a lead spike in Bobcat Cave. The yearly rate of detection remained low for cadmium and increased significantly for lead. Bobcat and Matthews Caves were visited monthly during this study period for water quality and biological monitoring. Water levels in Bobcat Cave permitted access for biological monitoring on eight occasions and cave shrimp were observed during four visits. None of the five shrimp observed had oocytes or attached ova. The highest number of shrimp observed was two on September 17, 2008. Since this study began in 1990, this was the first ever August sample where no shrimp were observed.

## INTRODUCTION

The Alabama cave shrimp, *Palaemonias alabamae* Smalley, 1961, is a rare, troglobitic shrimp protected since 1988 by the U.S. Fish and Wildlife Service (USFWS) under the Endangered Species Act (USFWS, 1988). It was last observed at the type locality, Shelta Cave in northwest Huntsville, in 1973. Subsequent sightings were at Bobcat Cave on the U.S. Army's Redstone Arsenal (RSA) in southwest Madison County, in a series of three hydrologically connected caves in southeast Madison County (Rheams and others, 1994), and in another cave in Colbert County near the Tennessee River (B. Kuhajda, personal communication, 2006).

The Endangered Species Act and the Recovery Plan (USFWS, 1996) for the Alabama cave shrimp provide for protection and study of the species on federal property, and to that end numerous studies have been conducted to monitor the population and its habitat in Bobcat Cave and vicinity (Moser and Rheams, 1992; Rheams and others, 1994; Campbell and others, 1996; McGregor and O'Neil, 1996, 2000, 2001, 2002, 2003, 2004, 2006, 2007; McGregor, O'Neil, and Campbell, 1997, 1999; McGregor, O'Neil, Rheams, and others, 1997; McGregor, O'Neil, and Gillett, 2005). These studies increased our knowledge of the recharge area of Bobcat Cave, long-term trends in water quality in Bobcat and Matthews Caves, seasonal water levels in Bobcat Cave, the quality and relationships of local surface and ground waters, and the life history and population trends of the Alabama cave shrimp. Results have been summarized in two publications (Burnett and others, 2003; McGregor and others, 2003). Two other cave shrimp populations are known: one was recently discovered in Muddy Cave south of Huntsville near the Tennessee River and the other is from Colbert County, approximately 70 miles to the west of RSA. Morphological differences between specimens from the Colbert County population and the Alabama cave shrimp suggest the need for a systematic revision of the genus.

In 2007, the Geological Survey of Alabama (GSA) was contracted by RSA to continue monitoring the Alabama cave shrimp population in Bobcat Cave, to report on its life history and population trends, and to monitor water-quality trends in Bobcat and Matthews Caves. This report summarizes the results of these studies.

## ACKNOWLEDGMENTS

Many individuals assisted with field work, provided valuable technical assistance, and otherwise contributed to the completion of this project. Danny Dunn of the Cultural and Environmental Resources Directorate coordinated access to Bobcat Cave. Bill Longgrear of RSA provided rainfall data for the Bobcat Cave vicinity. Dan Augenbaugh of RSA and his staff provided information regarding laser testing in the area near Bobcat Cave. Brett Smith of GSA assisted with field work.

## STUDY AREA

The study area is located near the western boundary of Redstone Arsenal, a U.S. Army facility in west-central Madison County, Alabama (fig. 1). Land in the immediate vicinity of the cave was formerly used as a cattle pasture. Implementation of a management plan for the cave shrimp within the past few years has resulted in retirement of the pasture as graze, and hardwood saplings have been planted throughout the area around Bobcat Cave. Urbanization is rapidly encroaching along Zierdt Road from the west. Redstone Arsenal is located within the Tennessee Valley district of the Highland Rim section of the Interior Low Plateaus physiographic province. This district is characterized by a plateau of moderate relief, composed of a chert belt to the north and a limestone plain along the Tennessee River with elevations ranging from approximately 600 to 800 feet above mean sea level (ft-msl) (Sapp and Emplaincourt,

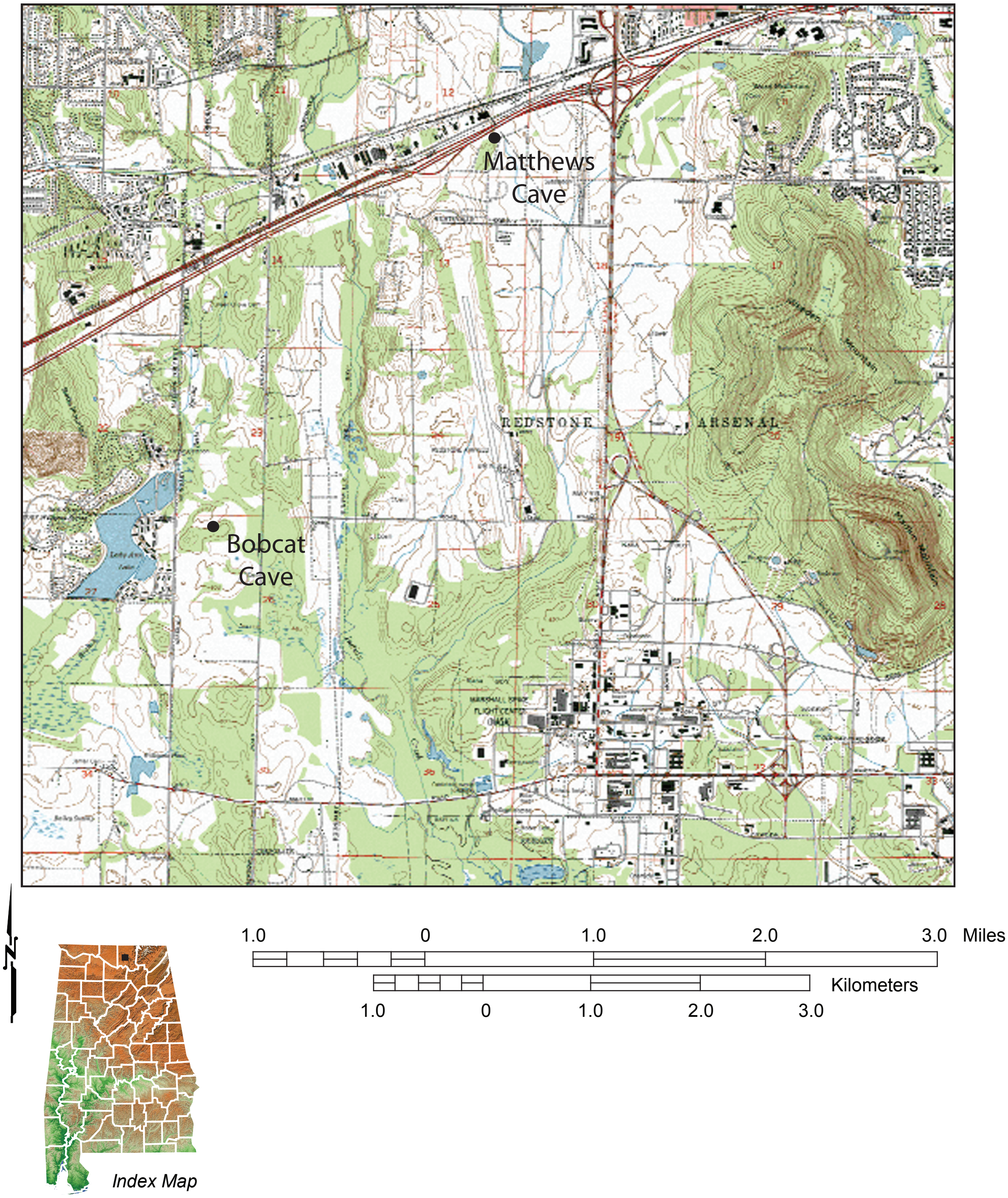


Figure 1. Study area in Madison County, Alabama.

1975). Some isolated hills or mountains up to 1,000 feet in elevation occur in this district in Madison County. Bobcat Cave is located within the limestone plain near the Tennessee River at an elevation of about 590 ft-msl.

The study area is underlain predominantly by thick sequences of carbonate rocks that generally dip to the south at approximately 20 feet per mile. Ground-water movement is generally from north to south throughout the area, although localized and often complex disruptions of this southerly flow pattern may occur. The Tennessee River, which forms the southern boundary of Madison County, is the dominant surface-water feature in the area and controls the direction of ground-water flow. Throughout Madison County, all surface-water systems flow in a general southerly direction and eventually discharge into the Tennessee River.

## METHODS

Water samples were collected monthly in Bobcat and Matthews Caves beginning in October 2007 and ending in September 2008. Chemical analyses of water samples were conducted in accordance with U.S. Environmental Protection Agency (USEPA 1973, 1983, 1988, 1990, 1991), Fishman and Friedman (1989), Greenberg and others (1992), and Wershaw and others (1987). Water samples were collected in accordance with the Standard Operating Procedures and Quality Assurance Manual of Alabama Department of Environmental Management (December 1986) and the Quality Assurance-Quality Control Plan for GSA (O'Neil and Meintzer, 1995).

The following parameters were measured *in situ* for each sample. Dissolved oxygen was measured in milligrams per liter (mg/L) using a Yellow Springs Instruments (YSI) Model 55 dissolved-oxygen meter. Hydrogen-ion concentration, specific conductance (measured in micro Siemens per centimeter (µS/cm)), and temperature were measured with a Horiba Water Checker Model U-10. Total residual chlorine was measured colorimetrically with a HACH Pocket Colorimeter II chlorine test kit. A collected sample was inoculated with a standard reagent powder pillow, allowed to stand for 3 to 5 minutes for the reaction to occur, then compared against a stream blank in the standardized color-comparison wheel. All meters were regularly checked against similar instruments in the GSA geochemical laboratory or against standard calibration solutions.

An integrated grab sample of water was collected monthly at each cave, and the following raw and filtered (0.45µm) individual samples were transported in Nasco whirl-pak sterilized bags, polyethylene bottles, or glass bottles to the GSA geochemical laboratory for analysis: one 4-oz filtered-chilled bags (4˚C), one 4-oz filtered-acidified (pH <2.0 with sulfuric acid) bag, one filtered-acidified (pH <2.0 with nitric acid) sample in a white polyethylene bottle, one raw-basic (pH >10 with NaOH) sample in a brown polyethylene bottle, one acidified (pH < 2.0 with sulfuric acid) raw sample in a small amber glass bottle, one raw sample in a small amber glass bottle for total organic carbon analysis, and one raw sample in a 1-liter white polyethylene bottle. These samples were analyzed for the parameters listed in table 1.

Biological monitoring consisted of monthly visual observations of the aquatic environment in Bobcat Cave when existing water levels permitted access and the recording of information regarding cave shrimp, such as number observed on each visit, seasonality of reproduction, and fecundity. Each visit involved walking along the margins of subterranean pools when water levels were low, or wading through pools when necessary and recording each shrimp observed. Information such as observer, time, date, unit of effort expended, and ambient condition was recorded in addition to life history notes such as relative size (if appreciably different from an average cave shrimp) and presence or absence and number of oocytes or attached ova, if possible. Observations usually took 15 minutes to 1 hour to accomplish per trip, with a mean observation time of 45 minutes. No shrimp were handled due to their diminutive size and to avoid physically damaging or unnecessarily stressing individuals. Similar observations have resulted from many sampling efforts since November 1990 of varying intensity and frequency. The current sampling effort is intended to provide a tool for the determination of the relative health of the population over time when compared to information gathered during previous studies. Any marked change in the number of cave shrimp observations or observations of gravid females during periods of time when they historically have been observed could then be compared to water-quality or water-level monitoring data taken during the same period to see if a relationship exists.

## RESULTS AND DISCUSSION

### WATER QUALITY

Twelve sets of water samples were collected from both Bobcat Cave and Matthews Cave from October 2007 through September 2008 (appendix A). Water in Bobcat Cave generally has had slightly higher specific conductance, and hence higher dissolved solids content, over the years compared to Matthews Cave (fig. 2), but from

Table 1. Water-quality parameters, lower limits of detection, and analytical methods.

| Parameter | Units | Lower limit of detection | Method [1] |
| --- | --- | --- | --- |
| Temperature | °C | -- | Electrometric, field |
| Dissolved oxygen | mg/L | 0.1 | Electrometric, field |
| Total residual chlorine | mg/L | 0.02 | Colorimetric, APHA 4500-Cl G |
| pH | units | -- | Electrometric, field |
| Alkalinity | mg/L as $CaCO_3$ | 3 | Colorimetric, EPA 310.2 |
| Specific conductance | $\mu S/cm^2$ | 1 | Electrometric, field |
| Total dissolved solids | mg/L | 10 | Gravimetric, USGS I-1750-85 |
| Hardness | mg/L as $CaCO_3$ | 1 | Calculated, USGS I-1340-85 |
| Silica | mg/L | 0.05 | ICP, EPA 200.7 |
| Sulfate | mg/L | 0.06 | Ion chromatography, EPA 300.0 |
| Bromide | mg/L | 0.05 | Ion chromatography, EPA 300.0 |
| Chloride | mg/L | 0.05 | Ion chromatography, EPA 300.0 |
| Fluoride | mg/L | 0.02 | Ion chromatography, USGS I-2057-85 |
| Bicarbonate | mg/L | 1 | Calculated, APHA 4500-CO2 D |
| Carbonate | mg/L | 1 | Calculated, APHA 4500-CO2 D |
| Ammonia as N | mg/L | 0.02 | Colorimetric, USGS I-2522-85 |
| Total Kjeldahl nitrogen | mg/L | 0.1 | Colorimetric, EPA 351.2 |
| Nitrite as N | mg/L | 0.01 | Ion chromatography, EPA 300.0 |
| Nitrate as N | mg/L | 0.020 | Ion chromatography, EPA 300.0 |
| Total nitrate-nitrite as N | mg/L | 0.020 | Ion chromatography, EPA 300.0 |
| Total phosphorus as P | mg/L | 0.020 | Colorimetric, EPA 365.1 |
| Orthophosphate as $PO_4$ | mg/L | 0.02 | Ion chromatography, EPA 300.0 |
| Arsenic | µg/L | 2 | Graphite-furnace atomic absorption, EPA 200.9 |
| Barium | µg/L | 2.0 | ICP, EPA 200.7 |
| Cadmium | µg/L | 4.0 | ICP, EPA 200.7 |
| Chromium | µg/L | 8 | ICP, EPA 200.7 |
| Copper | µg/L | 8 | ICP, EPA 200.7 |
| Iron | µg/L | 3 | ICP, EPA 200.7 |
| Lead | µg/L | 2 | Graphite-furnace atomic absorption, EPA 200.9 |
| Lithium | µg/L | 5 | ICP, EPA 200.7 |
| Manganese | µg/L | 2 | ICP, EPA 200.7 |
| Mercury | µg/L | 1 | Cold vapor atomic absorption, USGS I-2462-85 |
| Molybdenum | µg/L | 20 | ICP, EPA 200.7 |
| Nickel | µg/L | 10 | ICP, EPA 200.7 |
| Selenium | µg/L | 3 | Graphite-furnace atomic absorption, EPA 200.9 |
| Silver | µg/L | 10 | ICP, EPA 200.7 (GF, EPA 200.9) |
| Strontium | µg/L | 1 | ICP, EPA 200.7 |
| Zinc | µg/L | 4 | ICP, EPA 200.7 |
| Total organic carbon | mg/L | 0.4 | Combustion, EPA 415.1 |
| Chemical oxygen demand | mg/L | 30 | Colorimetric, EPA 410.4 |

1-APHA-American Public Health Association; EPA-Environmental Protection Agency: USGS-U.S. Geological Survey;
GF-graphite funace; ICP-inductively coupled plasma spectrometry

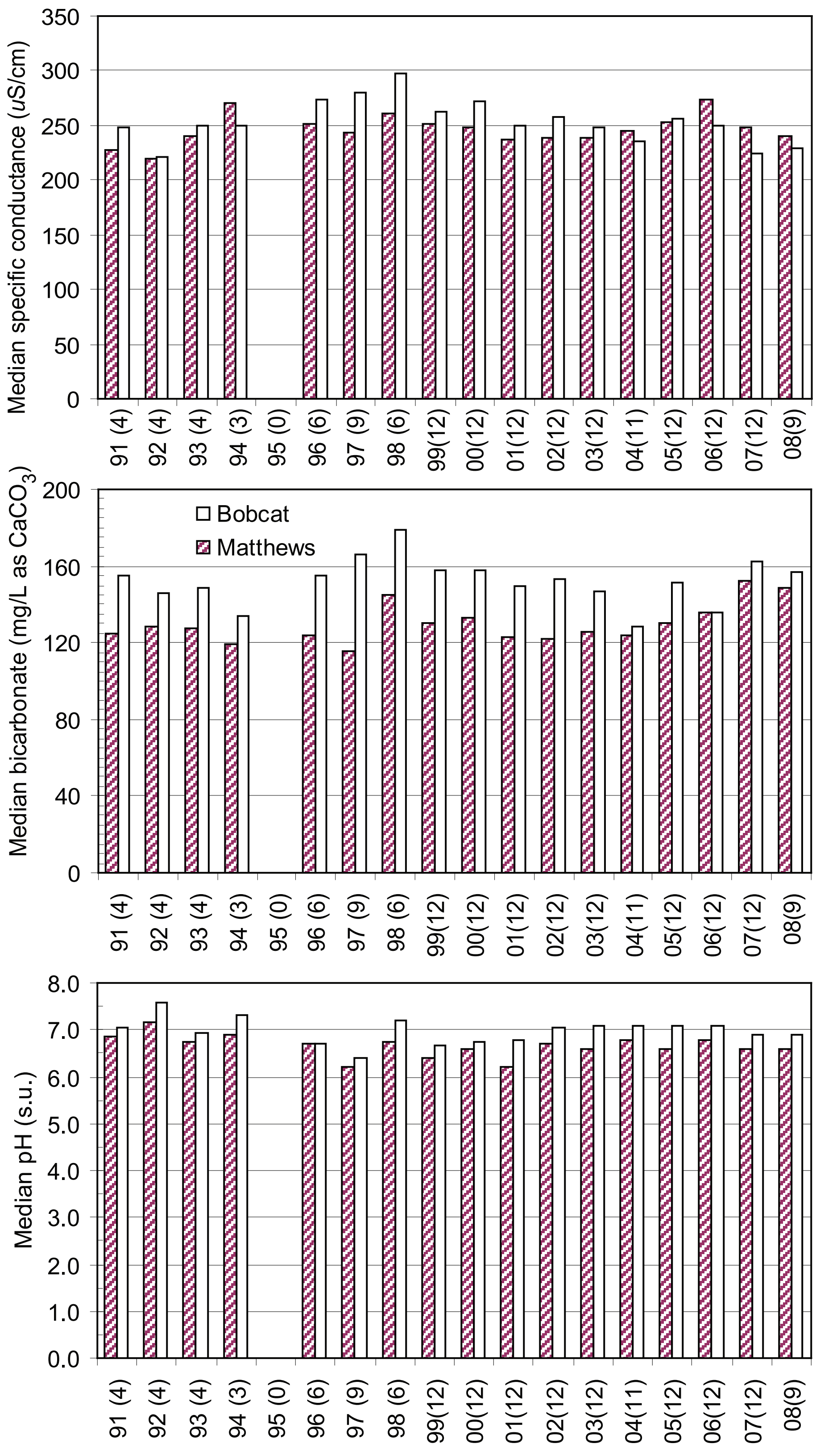


Figure 2. Plots of yearly median specific conductance, bicarbonate, and pH in Bobcat and Matthews Caves, 1991-2008. The number of samples collected each year is shown in parentheses.

2006 to 2008 conductance has been higher in Matthews Cave. The higher dissolved solids content is due to the presence of greater amounts of bicarbonate and calcium dissolved from the surrounding limestone. Other water-quality constituents and/or indicators of contamination, such as chloride, nitrate, and some trace metals, enter the ground water in both caves either through surface runoff directly into the cave or from deeper ground-water sources which eventually also supply water to the caves.

The alkalinity of a solution is defined as its capacity to react with and neutralize acid. The principal components of alkalinity are the dissolved carbon dioxide species carbonic acid, bicarbonate, and carbonate. At the pH values encountered in Bobcat and Matthews Caves, bicarbonate is the dominant form contributing to alkalinity. Contact with limestone, as in Bobcat and Matthews Caves, will generally saturate ground water for both bicarbonate and calcium. Bicarbonate in 2007-08 ranged from 139 to 190 mg/L with a median of 159 mg/L, which was very similar to the preceding year (2006-07) in Bobcat Cave, while the median bicarbonate in Matthews, was 152, and ranged from 129 to 174 mg/L, which was also very similar to the preceding year (table 2; fig. 2). Yearly median bicarbonate in Bobcat has ranged from a low of 128 mg/L in 2004 to a high of 179 mg/L in 1998, while this parameter in Matthews Cave has ranged from a low of 116 mg/L in 1997 to a high of 152 mg/L in 2007 (fig. 2). The pH of Bobcat Cave waters in 2007-08 ranged from 5.7 to 7.4 (median, 7.0), while pH of Matthews Cave ranged from 5.2 to 7.2 (median, 6.6) for the same period (table 2). Long-term trends of pH in both caves indicate that Matthews Cave waters are slightly more acidic than Bobcat Cave waters, with the median pH varying generally between 6.0 and 7.5 in both caves (fig. 2).

Chlorine is the most abundant of the halogens, and its compounds, which consist of chlorine and the common metallic elements, alkali metals, and alkaline earth metals, are readily soluble in water (Hem, 1989). The chloride form of chlorine is the only oxidation state of significance in water exposed to the atmosphere. The other oxidation states of chlorine are not found in significant quantities in natural waters, and their presence would be the result of contamination from a chlorinated water source. Chloride is present in rock types in concentrations lower than the other major constituents of natural water. As such, chloride concentrations are generally very low in natural fresh

Table 2. Summary water-quality data for Bobcat and Matthews Caves, October 2007 through September 2008.

| Parameter | Units[1] | LLD[2] | Bobcat | | | Matthews | | |
|---|---|---|---|---|---|---|---|---|
| | | | min | max | med | min | max | med |
| Temperature | °C | -- | 14 | 22 | 17 | 15 | 21 | 18 |
| Dissolved oxygen | mg/L | -- | 5.6 | 10.1 | 9.3 | 8.5 | 10.0 | 9.3 |
| TRC | mg/L | 0.02 | <.02 | 0.13 | 0.03 | <.02 | 0.39 | 0.04 |
| pH | units | s.u. | 5.7 | 7.4 | 7.0 | 5.2 | 7.2 | 6.6 |
| Alkalinity as $CaCO_3$ | mg/L | 3 | 114 | 156 | 131 | 106 | 143 | 125 |
| Conductance | µS/cm | 1 | 189 | 292 | 230 | 204 | 316 | 249 |
| TDS | mg/L | 10 | 123 | 190 | 150 | 133 | 205 | 162 |
| Hardness as $CaCO_3$ | mg/L | 1 | 106 | 148 | 130 | 109 | 145 | 132 |
| Sulfate | mg/L | 0.08 | 0.77 | 3.55 | 1.86 | 3.41 | 4.52 | 4.00 |
| Chloride | mg/L | 0.03 | 2.19 | 3.23 | 2.67 | 5.33 | 7.55 | 6.22 |
| Bromide | mg/L | 0.05 | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 |
| Fluoride | mg/L | 0.02 | <.02 | 0.02 | <.02 | <.02 | 0.022 | <.02 |
| Silica | mg/L | 0.06 | 7.18 | 8.22 | 7.55 | 7.28 | 8.83 | 8.33 |
| Bicarbonate | mg/L | 3 | 139 | 190 | 159 | 129 | 174 | 152 |
| Carbonate | mg/L | 1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ammonia as N | mg/L | 0.02 | <.02 | 0.09 | 0.03 | <.02 | 0.06 | 0.03 |
| Nitrite as N | mg/L | 0.006 | <.006 | <.006 | <.006 | <.006 | <.006 | <.006 |
| TKN | mg/L | 0.07 | <.006 | 0.360 | 0.180 | <.006 | 0.370 | 0.180 |
| Nitrate as N | mg/L | 0.006 | 0.358 | 0.898 | 0.541 | 2.000 | 2.480 | 2.255 |
| Total NOx as N | mg/L | 0.006 | 0.358 | 0.898 | 0.541 | 2.000 | 2.480 | 2.255 |
| Total phosphorus | mg/L | 0.01 | <.01 | 0.07 | 0.05 | <.01 | 0.13 | 0.05 |
| Orthophosphate as P | mg/L | 0.05 | <.05 | 0.08 | <.05 | <.05 | <.05 | <.05 |
| Arsenic | µg/L | 2 | <2 | 2.2 | <2 | <2 | <2 | <2 |
| Barium | µg/L | 1 | 10 | 64 | 37 | 14 | 62 | 41 |
| Cadmium | µg/L | 0.09 | <.09 | 0.64 | <.09 | <.09 | 5.2 | <.09 |
| Chromium | µg/L | 0.8 | <.8 | 1.3 | <.8 | <.8 | 0.8 | <.8 |
| Copper | µg/L | 5 | <5 | <5 | <5 | <5 | <5 | <5 |
| Iron | µg/L | 4 | <4 | 6 | <4 | <4 | 57 | <4 |
| Lead | µg/L | 0.9 | <.9 | 95.8 | 5.5 | <.9 | 35.7 | 7.1 |
| Lithium | µg/L | 8 | <8 | <8 | <8 | <8 | <8 | <8 |
| Manganese | µg/L | 0.8 | <.8 | 1.6 | <.8 | <.8 | 3.4 | <.8 |
| Mercury | µg/L | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Molybdenum | µg/L | 20 | <20 | <20 | <20 | <20 | <20 | <20 |
| Nickel | µg/L | 20 | <20 | 22 | <20 | <20 | 22 | <20 |
| Selenium | µg/L | 3 | <3 | <3 | <3 | <3 | <3 | <3 |
| Silver | µg/L | 10 | <10 | <10 | <10 | <10 | <10 | <10 |
| Strontium | µg/L | 0.5 | 41 | 63 | 52 | 45 | 66 | 56 |
| Zinc | µg/L | 4 | <4 | 48 | 16 | <4 | 32 | 23 |
| Total organic carbon | mg/L | 0.4 | <.4 | 2.26 | <.4 | <.4 | 1.72 | <.4 |
| COD | mg/L | 30 | 47 | 346 | 73 | 46 | 470 | 85 |

[1] - mg/L-milligrams per liter; *u*g/L-micrograms per liter; *u*S/cm-microSiemens per centimeter; °C-degrees Celcius

[2]- LLD lower limit of detection

waters, and their presence in quantity may indicate contamination. Chloride ranged from 2.19 to 3.23 mg/L (median, 2.67 mg/L) in Bobcat Cave and from 5.33 to 7.55 mg/L (median, 6.22 mg/L) in Matthews Cave (table 2) in 2007-08. The median concentrations of chloride in Matthews Cave have consistently varied in the range of about one and a half to two times the median chloride concentrations in Bobcat Cave over the period 1991 through 2008 (fig. 3), indicating that water in Matthews Cave likely has a greater connectivity to contaminated surface runoff and ground water. Yearly median chloride in Matthews Cave also shows a short-term increasing trend since 2006 and is likely related to increasing urbanization in the recharge area of Matthews Cave.

Sulfate concentrations ranged from 0.77 to 3.55 mg/L (median, 1.86 mg/L) in Bobcat and from 3.41 to 4.52 mg/L (median, 4.00 mg/L) in Matthews (table 2) in 2007-08. Over the period 1991 through 2005, median sulfate concentrations in Bobcat were greater than Matthews (fig. 3), except 1998 when median sulfate was slightly greater in Matthews and in 2006, 2007, and 2008 when median sulfate was substantially greater in Matthews. Like chloride, the short-term increasing trend of median sulfate since 2006 in Matthews Cave likely reflects increasing urbanization in the recharge area

The cycling of nitrogen through the atmosphere, hydrosphere, and lithosphere involves complex biological and chemical processes. Nitrogen in water occurs as nitrite ($NO_2^-$) and nitrate ($NO_3^-$) anions, as ammonium ($NH_4^+$) cations, and as organic solutes. Nitrate is stable in water over a variety of conditions, particularly in ground water, and is readily transported over long distances. Excessive nitrate concentrations (>10 mg/L $NO_3$ as N) may cause a condition known as methemoglobinemia in small children. Upon contact with sunlight, excess nitrate can contribute to nuisance algal blooms in surface waters. Nitrate ranged from 0.358 to 0.898 mg/L (median, 0.541 mg/L) in Bobcat and from 2.00 to 2.48 mg/L (median, 2.26 mg/L) in Matthews from 2007-08 (table 2). From 1991-2008, the median nitrate concentrations in Bobcat Cave have ranged from about 0.5 to just over 1.0 mg/L, whereas the median concentrations in Matthews Cave have ranged from less than 2.5 to near 3.5 mg/L (fig. 3). Ammonia was detected in ten samples from Bobcat Cave in 2007-08 (appendix) compared to eight samples in 2006-07, while ammonia was detected in ten samples from Matthews Cave in 2007-08 (appendix) and in ten samples in 2006-07. Phosphorus concentrations during 2007-08

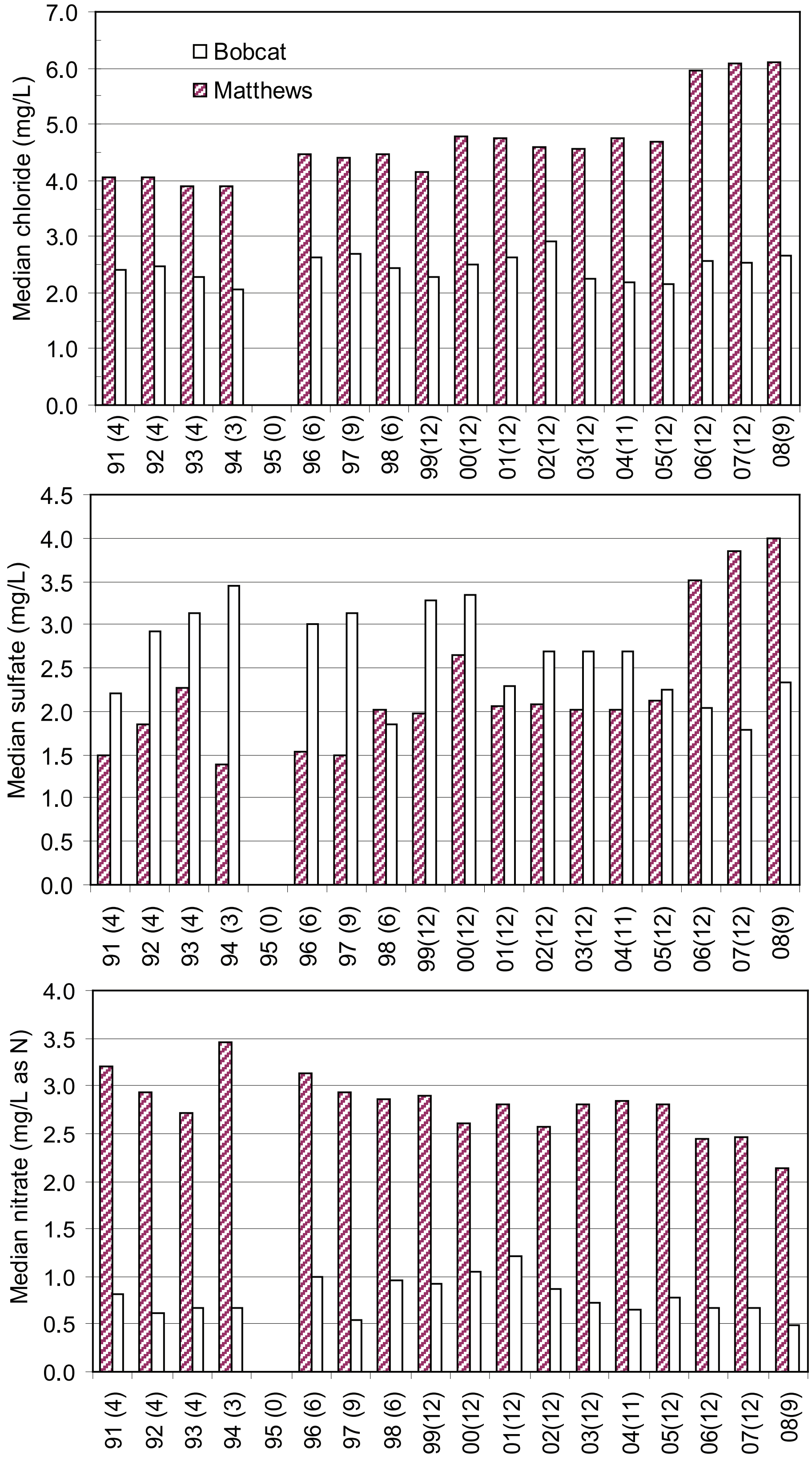


Figure 3. Plots of yearly median chloride, sulfate, and nitrate in Bobcat and Matthews Caves, 1991-2008. The number of samples collected is shown in parentheses.

were low in each cave with total dissolved phosphorus ranging from <.01 to 0.07 mg/L in Bobcat Cave and from <.01 to 0.13 mg/L in Matthews Cave. Median total phosphorus was 0.05 mg/L in both caves (table 2).

In natural waters unaffected by pollution, trace metals occur most of the time in low concentrations, generally <1.0 µg/L or undetectable. Elevated trace metal concentrations may indicate the presence of a contaminant source or a nearby ore deposit. Cadmium was detected in 3 each of 12 samples taken from Bobcat and Matthews Caves during 2007-08 (appendix). Cadmium concentrations in samples from Bobcat ranged from <.09 to 0.64 µg/L with a median of <.09 µg/L, while samples from Matthews Cave ranged from <.09 to 5.2 µg/L with a median of <.09 µg/L (table 2) in 2007-08. The maximum for Matthews Cave (5.2 µg/L), measured in April 2008, was the highest cadmium concentration measured in this cave since monitoring began in 1996 (fig. 4). The drinking water maximum contaminant level (MCL) for cadmium is 5.0 µg/L, the MCL for leachate from sanitary landfills is 10 µg/L, whereas the chronic and acute criteria for protection of aquatic life are 1.13 µg/L and 3.92 µg/L, respectively, calculated using a hardness of 100 mg/L. Data from 1996-2008 indicate the continued presence of cadmium in both Bobcat and Matthews Caves (fig. 5). However, the long term trend is decreasing cadmium detections and concentrations in both caves (figs. 4, 5), with the exception of the April 2008 spike observed in Matthews Cave. All samples collected in Matthews Cave during the period 1991-1994 were near or below detection limits, while a few detections were made in Bobcat Cave in 1992 and 1994 (fig. 4). Yearly cadmium detections over the period 1996-2008 have averaged 63 percent for Bobcat Cave and 62 percent for Matthews Cave.

Chromium was detected in 4 of 12 samples from Bobcat Cave in 2007-08 (appendix) and ranged from <.8 to 1.3 µg/L with a median of <.8 µg/L (table 2). Chromium was detected in 1 of 12 samples from Matthews Cave with a value of 1.3 µg/L. The drinking water MCL for chromium (III) is 100 µg/L, the landfill leachate MCL is 50 µg/L, while the chronic and acute aquatic-life criteria are 207 µg/L and 1,736 µg/L, respectively, for a hardness of 100 mg/L. The number of chromium detections decreased in Bobcat Cave from 1998-2000, rose to 75 percent in 2001, declined steadily to 25 percent in 2005, and had another rise and fall since 2006 (fig. 4).

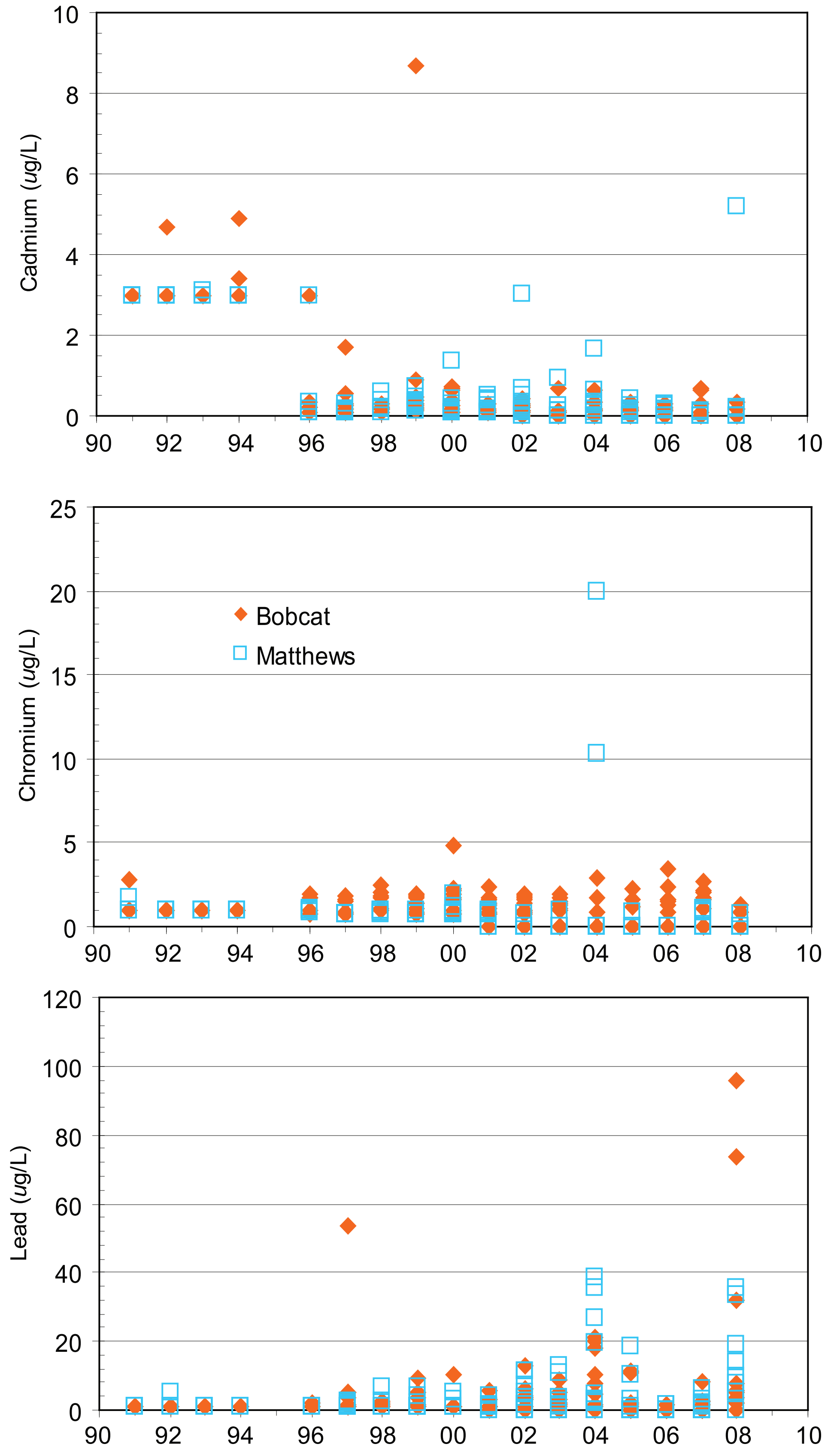


Figure 4. Selected trace metal concentrations in water from Bobcat and Matthews Caves, 1991-2008.

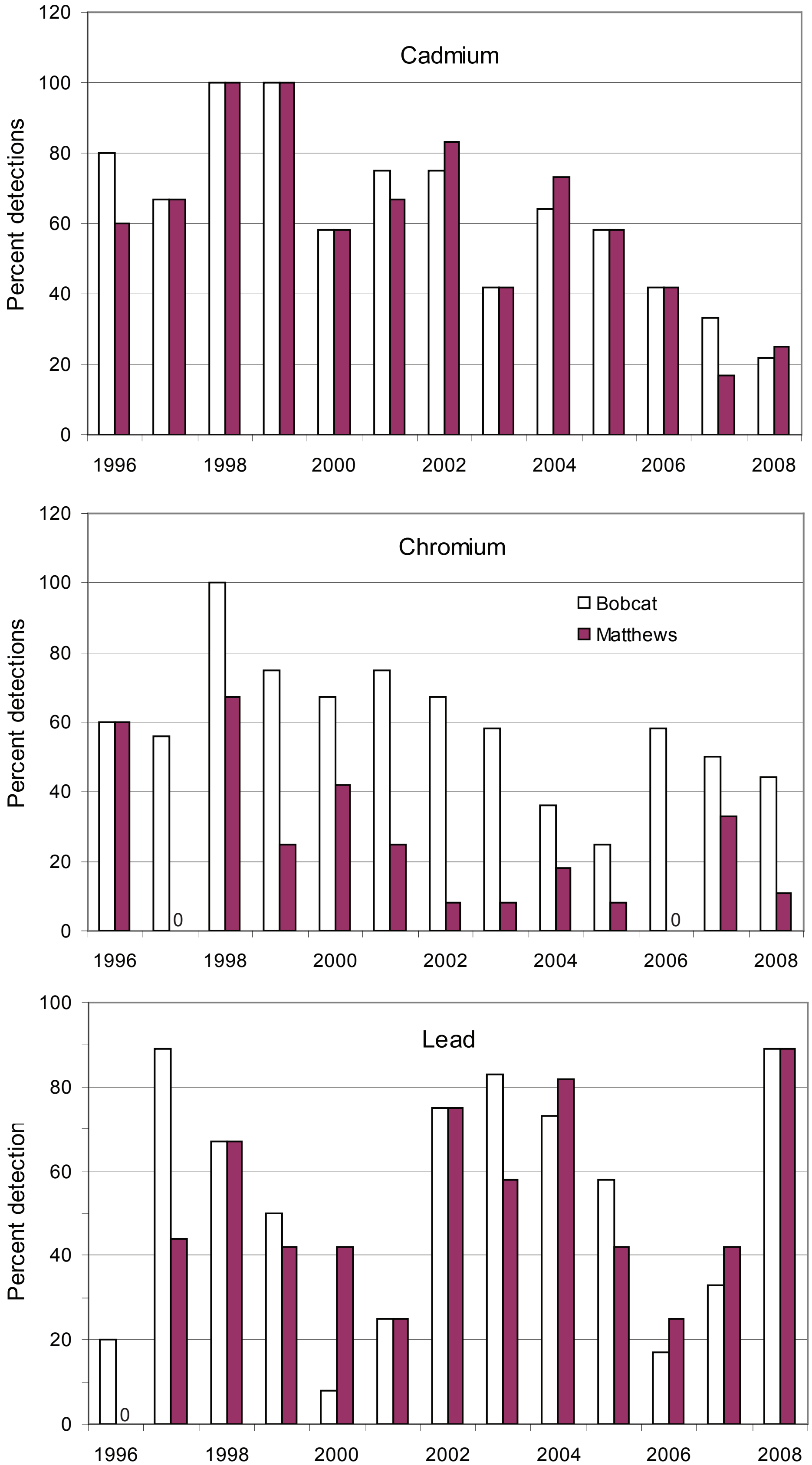


Figure 5. Yearly detection rates of cadmium, chromium, and lead in Bobcat and Matthews Caves, 1996-2008.

Chromium detections in Matthews Cave declined from a high of 67 percent in 1998 to lows of 8 percent in 2002, 2003, and 2005 and no detections in 2006. Detection rate has increased in recent years to 33 percent in 2007 and 17 percent in 2008 (fig. 5). Yearly chromium detections over the period 1996-2008 have averaged 58 percent for Bobcat Cave and 24 percent for Matthews Cave.

Lead was detected in 10 of 12 samples from Bobcat Cave in 2007-08 (appendix), ranging from <.9 to 95.8 µg/L with a median of 5.5 µg/L. Lead was also detected in 10 of 12 samples from Matthews Cave (appendix), ranging from <0.9 to 35.7 µg/L with a median of 7.1 µg/L (table 2). The drinking water MCL for lead is 15 µg/L, the landfill leachate criterion is 15 µg/L, while the chronic and acute aquatic-life criteria are 3.18 µg/L and 81.6 µg/L, respectively, for a hardness of 100 mg/L. The percentage of lead detections in Bobcat Cave steadily declined from a high of 89 percent in 1997 to 8 percent in 2000 before increasing to 25 percent in 2001, 75 percent in 2002, and 83 percent in 2003 (fig. 5). Lead detections declined progressively in each succeeding year to 73 percent in 2004, 58 percent in 2005, and to 17 percent in 2006. Detections have shown a steady increase since 2006 at 33 percent in 2007 and back up to 89 percent for nine samples collected in 2008. The maximum lead values for the past twelve years in Bobcat Cave are elevated well above the detection limit: 53 µg/L-1997, 2.5 µg/L-1998, 9.4 µg/L-1999,10.5 µg/L-2000, 5.8 µg/L-2001, 13.0 µg/L-2002, 8.6 µg/L-2003, 20.9 µg/L in 2004, 11.4 µg/L in 2005, 1.6 µg/L in 2006, 8.4 µg/L in 2007, and 95.8 µg/L through September in 2008. Similarly, the maximum lead values for Matthews Cave the past twelve years have also been well above detection limits: 2.5 µg/L-1997, 6.7 µg/L-1998, 6.6 µg/L-1999, 5.4 µg/L-2000, 4.3 µg/L-2001, 11.1 µg/L-2002, 12.7 µg/L-2003, 38.6 µg/L in 2004, 18.7 µg/L in 2005, 1.8 µg/L in 2006, 6.3 µg/L in 2007, and 35.7 µg/L through September in 2008.Yearly lead detections over the period 1996-2008 have averaged 53 percent for Bobcat Cave and 49 percent for Matthews Cave.

Median levels of several other toxic trace metals measured this year were less than detection limits in both caves and included arsenic, copper, lithium, manganese, mercury, molybdenum, nickel, selenium, and silver (table 2). Median zinc was 16 µg/L in Bobcat Cave and 23 µg/L in Matthews Cave. Median chemical oxygen demand (COD) was 73 mg/L in Bobcat Cave and 85 mg/L in Matthews Cave, while median total organic carbon was less than detection limit (0.4 mg/L) in both caves.

## CONTINUAL WATER-QUALITY AND WATER-LEVEL MONITORING

An automated water surface elevation, temperature, and specific conductance monitor has operated in Bobcat Cave from November 1992 through September 2008. Results of previous water-level investigations in and around Bobcat Cave (McGregor, O'Neil, and Campbell, 1997) indicate that the hydrology of Bobcat Cave is likely controlled by two distinct factors: (1) ground water originating in the soils and karst terrane around the cave, and (2) the degree to which Bobcat Cave is connected to the land surface by direct conduits through which surface runoff enters the cave during storm events.

Plots of daily parameter measurements for specific conductance, temperature, and surface water elevation are depicted in figure 6, along with daily rainfall records provided by RSA. The rainfall station is located about 5 miles to the southeast of Bobcat Cave. Some of the rainfall events, particularly isolated summer storms, cannot be directly correlated with rising water level in Bobcat Cave. However, widespread rains, as occur from fall through spring months, do correlate with rising water levels in the cave.

Average water level in Bobcat Cave is highest from January through May and lowest from August through October (fig. 6). Rising ground water during winter months increases the base level of Bobcat Cave by approximately 6 feet, from 575 ft-msl to around 581 ft-msl. Runoff associated with storm fronts can temporarily raise the surface elevation another 5 feet to the maximum level of 586 feet (fig. 6). Water exits through fissures and cracks generally to the east of Bobcat Cave at 585 to 586 feet. Monthly variation of water level is highest from November through April, when Bobcat receives greater quantities of surface runoff. Water is present only in isolated pools and windows at 575 feet. Water level in Bobcat Cave averaged 578.7 ft-msl over the period 1993 through 2008.

Bobcat Cave has a very stable water temperature regime throughout the year, averaging 14.3˚C from 1993-2008. Temperature generally varies 2˚C throughout the year, ranging from a low of 12˚C to a high around 16˚C (fig. 6). The highest average monthly water temperature occurs in November and December, while the lowest occurs

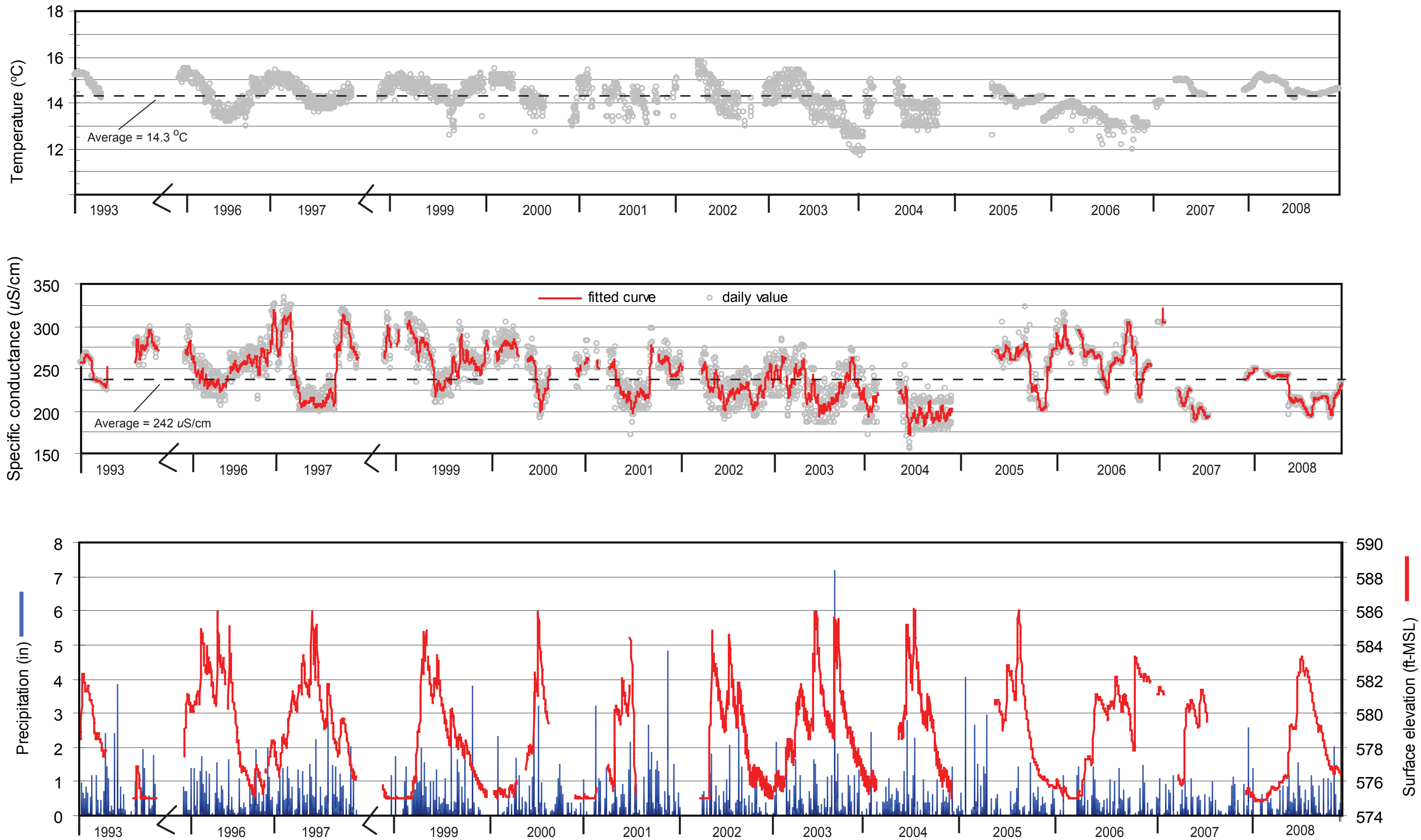


Figure 5. Daily water-quality monitoring data for Bobcat Cave, 1993-2008.

in May. The water temperature regime in Bobcat Cave appeared to be vulnerable to flooding effects of surface-water runoff. Several storm events (July 1996, May 1999, April 2000 and 2001, May 2002, September 2003) briefly lowered temperature by 0.5 to 1.0˚C below the average for that time of year with rapid recovery to ambient water temperature.

The quality of ground water in Bobcat Cave is controlled by several mechanisms including surface runoff into the cave, solubility conditions between the surrounding limestone and water, and quality of ground water from deep aquifers that contribute to the cave's water supply. Average specific conductance from 1993 through 2008 was 242 µS/cm, ranging from 155 to 333 µS/cm (fig. 6). Specific conductance spikes occurred when cave waters were low and rapidly received surface runoff from summer and fall storms. A significant jump in average specific conductance from May to June may indicate a transitional period during the annual hydrologic cycle when deeper ground water with a higher mineral content begins to dominate Bobcat Cave's water supply.

## BIOLOGICAL MONITORING

Bobcat Cave was visited monthly from October 2007 to September 2008 (appendix B). On four occasions (February to May) the cave was filled with water, and no observations of cave shrimp were possible beyond the foot of the entrance slope. Cave shrimp were observed during four of eight visits when the cave was accessible and a total of 5 shrimp were observed for the entire year and none of these five shrimp had visible oocytes. The highest number of shrimp observed was two on September 17, 2008 (appendix B). The most cave shrimp sightings are in July and August in Bobcat Cave, but this year only one shrimp was observed in July, perhaps due to extremely low water levels attributable to a continuing severe drought condition.

Information concerning long-term trends in the shrimp population in Bobcat Cave (1990 to present) is found in figure 7. July and August are the months when shrimp observations are most prevalent, each month having at least one observation of 40 or more shrimp in one or more visits. The upper graph provides a comparison of monthly shrimp observations and the total number of observation trips into the cave, as well as the average monthly surface water elevation. The reason that relatively large numbers

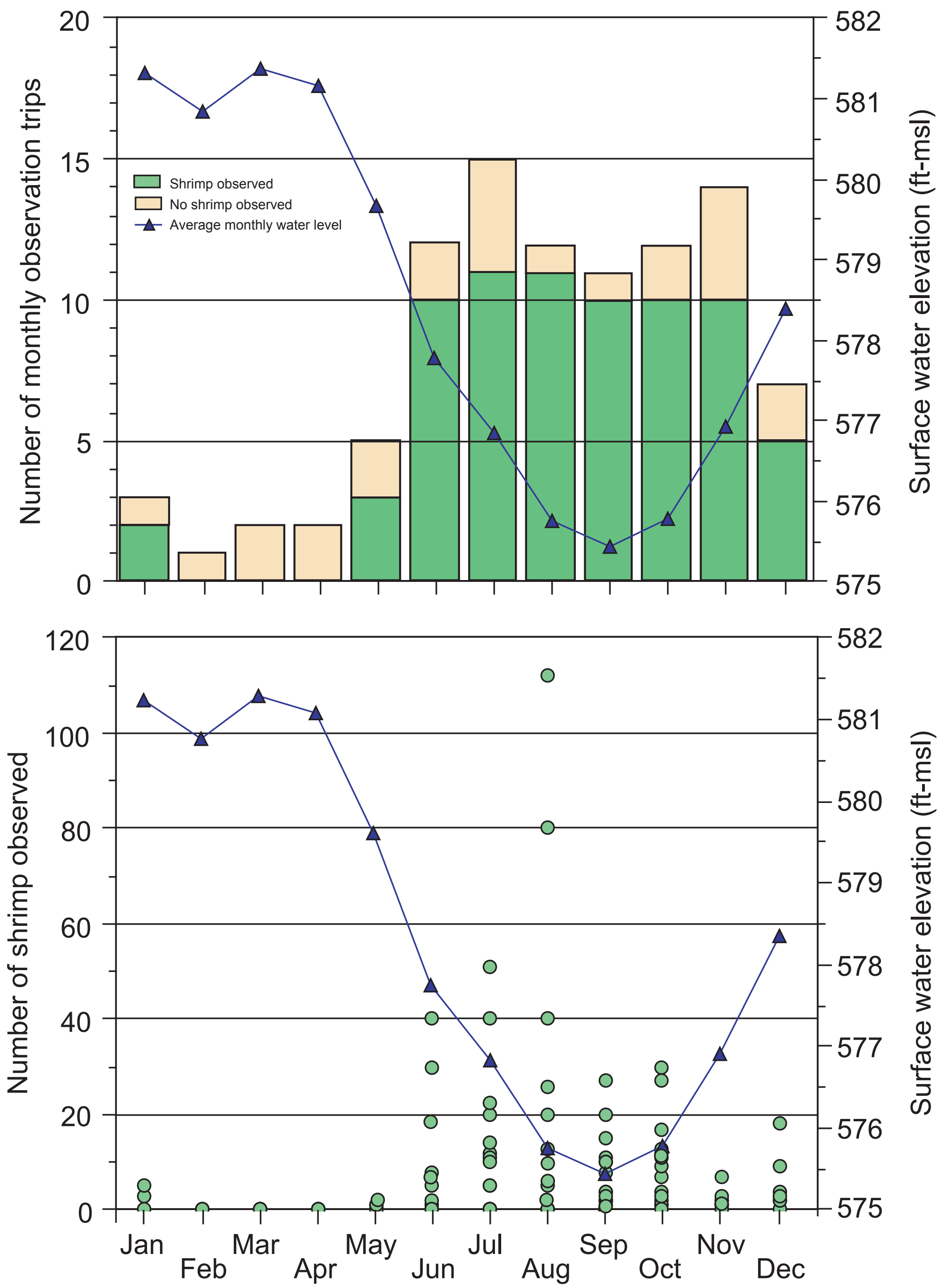


Figure 7. Shrimp observations and counts in Bobcat Cave, 1990-2008.

of shrimp are observed during June through August is linked to the low water levels during those months and increased cave area for searching. However, the lowest average monthly water elevation occurs in September, when counts have never risen above 27 individuals observed in one visit. We suspect a behavioral trait such as migration to deeper ground water with receding water level to prevent individuals from becoming stranded in isolated pools. As shown in the upper graph of figure 7, shrimp have been observed in almost every visit in September, probably a result of some shrimp that became stranded in isolated pools and couldn't escape to lower cave levels. As stated before, shrimp have never been observed in Bobcat Cave during the months of February through April, due to the fact that the cave is inaccessible during that period. Shrimp have only been observed on three occasions during the collective months of May probably again due to high water levels and restricted access. The inverse may be true for the fall and winter months, when the water level begins rising with seasonal rainfall. Conditions for observations are generally good at this time, but the shrimp are still inaccessible and therefore relatively few are observed.

## CONCLUSIONS AND RECOMMENDATIONS

Based on the results found in this and previous studies of Bobcat and Matthews Caves, we make the following recommendations:

> Monitoring of the shrimp population within the cave should be continued, and information should be gathered and compiled into the existing database to monitor population trends.

> Monitoring of the physical and chemical properties of cave waters should continue with special attention placed on the levels and trends of potential toxins, such as lead, cadmium, and other parameters associated with runoff from an increasingly urban landscape. Increasing urbanization around RSA will likely affect ground water, which may have consequences for Bobcat Cave and the resident Alabama cave shrimp population.

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## APPENDIX A

Water-quality sampling data
2007-2008

| Site<br>Date | Units | Bobcat<br>16-Oct-07 | Bobcat<br>14-Nov-07 | Bobcat<br>11-Dec-07 | Bobcat<br>15-Jan-08 | Bobcat<br>21-Feb-08 | Bobcat<br>18-Mar-08 |
|---|---|---|---|---|---|---|---|
| Time | 24-hr | 11:45 | 13:25 | 11:00 | 12:10 | 13:00 | 10:30 |
| Temperature | °C | 19 | 17 | 17 | 14 | 14 | 16 |
| Dissolved oxygen | mg/L | 8.6 | 6.0 | 8.4 | 5.6 | 9.3 | 9.4 |
| TRC | mg/L | <.02 | 0.13 | 0.03 | 0.03 | <.02 | 0.02 |
| pH | units | 7.1 | 7.4 | 6.8 | 7.3 | 5.7 | 6.8 |
| Alkalinity as $CaCO_3$ | mg/L | 156 | 148 | 144 | 153 | 125 | 114 |
| Conductance | µS/cm | 292 | 245 | 292 | 231 | 263 | 239 |
| TDS | mg/L | 168 | 161 | 155 | 163 | 137 | 127 |
| Hardness as $CaCO_3$ | mg/L | 148 | 139 | 136 | 140 | 120 | 107 |
| Sulfate | mg/L | 0.77 | 1.85 | 1.70 | 1.87 | 2.34 | 3.54 |
| Chloride | mg/L | 2.44 | 3.23 | 2.42 | 2.65 | 2.30 | 2.19 |
| Bromide | mg/L | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 |
| Fluoride | mg/L | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 |
| Silica | mg/L | 8.22 | 8.06 | 7.61 | 7.96 | 7.33 | 7.49 |
| Bicarbonate | mg/L | 190 | 180 | 175 | 186 | 152 | 139 |
| Carbonate | mg/L | <1 | <1 | <1 | <1 | <1 | <1 |
| Ammonia as N | mg/L | 0.025 | 0.049 | <.02 | 0.031 | 0.025 | 0.034 |
| Nitrite as N | mg/L | <.006 | <.006 | <.006 | <.006 | <.006 | <.006 |
| TKN | mg/L | 0.18 | <.07 | <.07 | 0.07 | 0.25 | 0.09 |
| Nitrate as N | mg/L | 0.820 | 0.648 | 0.545 | 0.494 | 0.537 | 0.442 |
| Total NOx as N | mg/L | 0.820 | 0.648 | 0.545 | 0.494 | 0.537 | 0.442 |
| Total phosphorus | mg/L | 0.035 | <.01 | 0.023 | <.01 | <.01 | 0.072 |
| Orthophosphate as P | mg/L | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 |
| Arsenic | µg/L | <2 | <2 | <2 | <2 | <2 | <2 |
| Barium | µg/L | 16.9 | 64.3 | 16.3 | 15.1 | 43.1 | 10.3 |
| Cadmium | µg/L | <.09 | 0.64 | <.09 | <.09 | <.09 | <.09 |
| Chromium | µg/L | <.8 | <.8 | <.8 | <.8 | <.8 | 0.9 |
| Copper | µg/L | <5 | <5 | <5 | <5 | <5 | <5 |
| Iron | µg/L | 5 | <4 | <4 | <4 | <4 | <4 |
| Lead | µg/L | <.9 | 2.4 | 8.4 | 5.4 | 7.7 | 3.4 |
| Lithium | µg/L | <8 | <8 | <8 | <8 | <8 | <8 |
| Manganese | µg/L | <.8 | <.8 | <.8 | <.8 | <.8 | <.8 |
| Mercury | µg/L | <1 | <1 | <1 | <1 | <1 | <1 |
| Molybdenum | µg/L | <20 | <20 | <20 | <20 | <20 | <20 |
| Nickel | µg/L | <20 | <20 | <20 | <20 | 22 | <20 |
| Selenium | µg/L | <3 | <3 | <3 | <3 | <3 | <3 |
| Silver | µg/L | <10 | <10 | <10 | <10 | <10 | <10 |
| Strontium | µg/L | 62.5 | 57.7 | 55.4 | 52.2 | 47.7 | 41.4 |
| Zinc | µg/L | <4 | 47.6 | 7.6 | 7.3 | 15.3 | <4 |
| Total organic carbon | mg/L | <.4 | 1.58 | <.4 | <.4 | <.4 | 2.26 |
| COD | mg/L | 58 | 56 | 271 | 346 | 57 | 66 |

| Site<br>Date | Units | Bobcat<br>16-Apr-08 | Bobcat<br>15-May-08 | Bobcat<br>17-Jun-08 | Bobcat<br>24-Jul-08 | Bobcat<br>13-Aug-08 | Bobcat<br>17-Sep-08 |
|---|---|---|---|---|---|---|---|
| Time | 24-hr | 12:45 | 13:50 | 12:05 | 13:15 | 12:00 | 12:50 |
| Temperature | °C | 17 | 17 | 21 | 22 | 18 | 16 |
| Dissolved oxygen | mg/L | 9.5 | 9.3 | 9.2 | 10.1 | 9.7 | 8.3 |
| TRC | mg/L | <.02 | <.02 | 0.08 | 0.07 | 0.04 | 0.05 |
| pH | units | 7.4 | 7.4 | 7 | 6.9 | 6.9 | 6.9 |
| Alkalinity as $CaCO_3$ | mg/L | 115 | 116 | 129 | 129 | 132 | 139 |
| Conductance | μS/cm | 189 | 193 | 214 | 221 | 229 | 229 |
| TDS | mg/L | 130 | 126 | 132 | 144 | 148 | 100 |
| Hardness as $CaCO_3$ | mg/L | 111 | 106 | 115 | 126 | 135 | 135 |
| Sulfate | mg/L | 3.55 | 2.94 | 2.35 | 0.95 | 1.17 | 0.93 |
| Chloride | mg/L | 2.68 | 2.38 | 3.17 | 2.77 | 2.78 | 2.78 |
| Bromide | mg/L | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 |
| Fluoride | mg/L | <.02 | <.02 | <.02 | <.02 | <.02 | 0.02 |
| Silica | mg/L | 7.44 | 7.20 | 7.91 | 7.87 | 7.18 | 7.25 |
| Bicarbonate | mg/L | 140 | 141 | 157 | 157 | 161 | 169 |
| Carbonate | mg/L | <1 | <1 | <1 | <1 | <1 | <1 |
| Ammonia as N | mg/L | 0.043 | 0.086 | 0.032 | 0.021 | <.02 | 0.055 |
| Nitrite as N | mg/L | <.006 | <.006 | <.006 | <.006 | <.006 | <.006 |
| TKN | mg/L | 0.36 | 0.19 | 0.18 | 0.21 | 0.16 | 0.31 |
| Nitrate as N | mg/L | 0.358 | 0.360 | 0.507 | 0.744 | 0.742 | 0.898 |
| Total NOx as N | mg/L | 0.358 | 0.360 | 0.507 | 0.744 | 0.742 | 0.898 |
| Total phosphorus | mg/L | 0.057 | 0.071 | 0.066 | 0.063 | 0.052 | 0.065 |
| Orthophosphate as P | mg/L | <.05 | <.05 | <.05 | <.05 | <.05 | 0.08 |
| Arsenic | μg/L | <2 | 2.2 | <2 | <2 | <2 | <2 |
| Barium | μg/L | 34.8 | 41.2 | 32.8 | 39.8 | 48.7 | 51.1 |
| Cadmium | μg/L | <.09 | <.09 | <.09 | <.09 | 0.16 | 0.35 |
| Chromium | μg/L | <.8 | <.8 | 0.9 | 1.3 | 1.3 | <.8 |
| Copper | μg/L | <5 | <5 | <5 | <5 | <5 | <5 |
| Iron | μg/L | <4 | <4 | <4 | <4 | 6.2 | <4 |
| Lead | μg/L | 5.6 | 73.9 | 32.1 | 95.8 | <.9 | 2.2 |
| Lithium | μg/L | <8 | <8 | <8 | <8 | <8 | <8 |
| Manganese | μg/L | <.8 | <.8 | 1.6 | <.8 | <.8 | <.8 |
| Mercury | μg/L | <1 | <1 | <1 | <1 | <1 | <1 |
| Molybdenum | μg/L | <20 | <20 | <20 | <20 | <20 | <20 |
| Nickel | μg/L | <20 | <20 | <20 | <20 | <20 | <20 |
| Selenium | μg/L | <3 | <3 | <3 | <3 | <3 | <3 |
| Silver | μg/L | <10 | <10 | <10 | <10 | <10 | <10 |
| Strontium | μg/L | 46.4 | 48.4 | 50.8 | 51.9 | 56.6 | 54.8 |
| Zinc | μg/L | 16.2 | 25.5 | <4 | 22.8 | 28.7 | 21.5 |
| Total organic carbon | mg/L | <.4 | <.4 | <.4 | <.4 | <.4 | <.4 |
| COD | mg/L | 70 | 99 | 107 | 75 | 47 | 98 |

| Site<br>Date | Units | Matthews<br>16-Oct-07 | Matthews<br>14-Nov-07 | Matthews<br>11-Dec-07 | Matthews<br>15-Jan-08 | Matthews<br>21-Feb-08 | Matthews<br>18-Mar-08 |
|---|---|---|---|---|---|---|---|
| Time | 24-hr | 10:50 | 12:10 | 11:55 | 10:45 | 12:15 | 11:30 |
| Temperature | °C | 21 | 18 | 19 | 15 | 16 | 17 |
| Dissolved oxygen | mg/L | 9.3 | 9.3 | 8.8 | 8.8 | 9.3 | 8.8 |
| TRC | mg/L | 0.39 | <.02 | 0.04 | 0.03 | 0.02 | 0.02 |
| pH | units | 6.6 | 7.1 | 7.2 | 6.5 | 5.2 | 6.8 |
| Alkalinity as $CaCO_3$ | mg/L | 140 | 143 | 125 | 142 | 119 | 106 |
| Conductance | µS/cm | 316 | 272 | 243 | 241 | 307 | 204 |
| TDS | mg/L | 174 | 177 | 155 | 169 | 148 | 134 |
| Hardness as $CaCO_3$ | mg/L | 145 | 145 | 129 | 137 | 122 | 109 |
| Sulfate | mg/L | 4.32 | 4.52 | 3.98 | 4.31 | 3.98 | 3.74 |
| Chloride | mg/L | 6.79 | 7.55 | 6.21 | 6.12 | 5.59 | 5.33 |
| Bromide | mg/L | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 |
| Fluoride | mg/L | <.02 | <.02 | <.02 | <.02 | <.02 | <.02 |
| Silica | mg/L | 8.83 | 8.77 | 8.73 | 8.47 | 8.32 | 8.10 |
| Bicarbonate | mg/L | 171 | 174 | 152 | 173 | 145 | 129 |
| Carbonate | mg/L | <1 | <1 | <1 | <1 | <1 | <1 |
| Ammonia as N | mg/L | <.02 | 0.020 | 0.021 | <.02 | 0.033 | 0.046 |
| Nitrite as N | mg/L | <.006 | <.006 | <.006 | <.006 | <.006 | <.006 |
| TKN | mg/L | 0.16 | <.07 | 0.20 | 0.08 | 0.29 | 0.09 |
| Nitrate as N | mg/L | 2.410 | 2.430 | 2.080 | 2.000 | 2.060 | 2.330 |
| Total NOx as N | mg/L | 2.410 | 2.430 | 2.080 | 2.000 | 2.060 | 2.330 |
| Total phosphorus | mg/L | 0.029 | 0.023 | 0.023 | <.01 | <.01 | 0.068 |
| Orthophosphate as P | mg/L | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 |
| Arsenic | µg/L | <2 | <2 | <2 | <2 | <2 | <2 |
| Barium | µg/L | 17.2 | 62.1 | 52.9 | 14.9 | 49.2 | 13.7 |
| Cadmium | µg/L | <.09 | <.09 | <.09 | <.09 | <.09 | <.09 |
| Chromium | µg/L | <.8 | <.8 | <.8 | <.8 | <.8 | <.8 |
| Copper | µg/L | <5 | <5 | <5 | <5 | <5 | <5 |
| Iron | µg/L | 4 | <4 | <4 | <4 | <4 | <4 |
| Lead | µg/L | <.9 | 2.9 | 6.3 | 5.4 | 7.9 | 5.3 |
| Lithium | µg/L | <8 | <8 | <8 | <8 | <8 | <8 |
| Manganese | µg/L | <.8 | <.8 | <.8 | <.8 | <.8 | <.8 |
| Mercury | µg/L | <1 | <1 | <1 | <1 | <1 | <1 |
| Molybdenum | µg/L | <20 | <20 | <20 | <20 | <20 | <20 |
| Nickel | µg/L | 22 | 21 | <20 | <20 | <20 | <20 |
| Selenium | µg/L | <3 | <3 | <3 | <3 | <3 | <3 |
| Silver | µg/L | <10 | <10 | <10 | <10 | <10 | <10 |
| Strontium | µg/L | 66.0 | 62.6 | 54.0 | 53.9 | 51.0 | 45.0 |
| Zinc | µg/L | 9.2 | 14.1 | 31.1 | 5.8 | 25.8 | <4 |
| Total organic carbon | mg/L | <.4 | <.4 | <.4 | <.4 | 1.72 | 1.11 |
| COD | mg/L | 46 | 83 | 151 | 470 | 46 | 87 |

| Site<br>Date | Units | Matthews<br>16-Apr-08 | Matthews<br>15-May-08 | Matthews<br>17-Jun-08 | Matthews<br>24-Jul-08 | Matthews<br>13-Aug-08 | Matthews<br>17-Sep-08 |
|---|---|---|---|---|---|---|---|
| Time | 24-hr | 12:00 | 13:00 | 11:00 | 11:30 | 10:20 | 11:15 |
| Temperature | °C | 17 | 18 | 21 | 21 | 19 | 18 |
| Dissolved oxygen | mg/L | 9.3 | 8.5 | 10.0 | 10 | 9.7 | 8.8 |
| TRC | mg/L | 0.04 | 0.22 | 0.06 | 0.08 | <.02 | <.02 |
| pH | units | 6.7 | 6.8 | 6.5 | 6.6 | 6.5 | 6.6 |
| Alkalinity as $CaCO_3$ | mg/L | 108 | 121 | 122 | 132 | 128 | 125 |
| Conductance | µS/cm | 212 | 228 | 232 | 254 | 260 | 267 |
| TDS | mg/L | 139 | 150 | 131 | 165 | 162 | 106 |
| Hardness as $CaCO_3$ | mg/L | 113 | 120 | 123 | 139 | 138 | 134 |
| Sulfate | mg/L | 3.41 | 3.70 | 4.01 | 4.44 | 4.44 | 3.89 |
| Chloride | mg/L | 5.76 | 5.91 | 7.06 | 6.49 | 6.43 | 6.22 |
| Bromide | mg/L | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 |
| Fluoride | mg/L | <.02 | 0.02 | <.02 | <.02 | <.02 | 0.02 |
| Silica | mg/L | 8.02 | 8.38 | 7.84 | 8.34 | 7.28 | 8.19 |
| Bicarbonate | mg/L | 132 | 147 | 149 | 161 | 156 | 152 |
| Carbonate | mg/L | <1 | <1 | <1 | <1 | <1 | <1 |
| Ammonia as N | mg/L | 0.033 | 0.063 | 0.039 | 0.031 | 0.021 | 0.047 |
| Nitrite as N | mg/L | <.006 | <.006 | <.006 | <.006 | <.006 | <.006 |
| TKN | mg/L | 0.29 | 0.23 | 0.12 | <.07 | 0.37 | 0.22 |
| Nitrate as N | mg/L | 2.460 | 2.290 | 2.480 | 2.220 | 2.190 | 2.140 |
| Total NOx as N | mg/L | 2.460 | 2.290 | 2.480 | 2.220 | 2.190 | 2.140 |
| Total phosphorus | mg/L | 0.054 | 0.126 | 0.071 | 0.068 | 0.051 | 0.062 |
| Orthophosphate as P | mg/L | <.05 | <.05 | <.05 | <.05 | <.05 | <.05 |
| Arsenic | µg/L | <2 | <2 | <2 | <2 | <2 | <2 |
| Barium | µg/L | 44.6 | 37.5 | 30.5 | 46.4 | 33.3 | 48.5 |
| Cadmium | µg/L | 5.2 | <.09 | <.09 | <.09 | 0.18 | 0.22 |
| Chromium | µg/L | <.8 | 0.8 | <.8 | <.8 | <.8 | <.8 |
| Copper | µg/L | <5 | <5 | <5 | <5 | <5 | <5 |
| Iron | µg/L | <4 | <4 | <4 | <4 | 56.8 | <4 |
| Lead | µg/L | 9.6 | 33.4 | 19.1 | 35.7 | <.9 | 14.1 |
| Lithium | µg/L | <8 | <8 | <8 | <8 | <8 | <8 |
| Manganese | µg/L | <.8 | 1.4 | 1.8 | 3.4 | <.8 | <.8 |
| Mercury | µg/L | <1 | <1 | <1 | <1 | <1 | <1 |
| Molybdenum | µg/L | <20 | <20 | <20 | <20 | <20 | <20 |
| Nickel | µg/L | <20 | <20 | <20 | <20 | <20 | <20 |
| Selenium | µg/L | <3 | <3 | <3 | <3 | <3 | <3 |
| Silver | µg/L | <10 | <10 | <10 | <10 | <10 | <10 |
| Strontium | µg/L | 48.6 | 56.5 | 56.4 | 58.8 | 62.2 | 54.6 |
| Zinc | µg/L | 22.2 | 32.2 | <4 | 23.1 | 23.4 | 23.3 |
| Total organic carbon | mg/L | <.4 | <.4 | <.4 | <.4 | <.4 | <.4 |
| COD | mg/L | 143 | 60 | 104 | 69 | 72 | 95 |

## APPENDIX B

Chronological list of recent Alabama cave shrimp observations in Bobcat Cave, November 1990-September 2008

| Date | Number observed | Notes[1] |
|---|---|---|
| November, 10, 1990 | 0 | |
| November 11, 1990 | 0 | |
| December 12, 1990 | 3 | |
| December 16, 1990 | 18 | |
| July 22, 1991 | 51 | Unknown number females with oocytes or attached ova |
| July 24, 1991 | 0 | |
| August 16, 1991 | 40 | At least 15 females with oocytes or attached ova |
| August 17, 1991 | 0 | |
| August 21, 1991 | 16 | Three females with oocytes or attached ova |
| September 11, 1991 | 2 | |
| September 16, 1991 | 2 | |
| September 18, 1991 | 4 | |
| September 20, 1991 | 1 | |
| October 4, 1991 | 0 | |
| October 28, 1991 | 30 | Four females with oocytes or attached ova |
| November 14, 1991 | 1 | |
| November 29, 1991 | 2 | |
| December 9, 1991 | 0 | |
| March 11, 1992 | 0 | |
| May 6, 1992 | 0 | |
| May 7, 1992 | 0 | |
| May 15, 1992 | 1 | Reportedly 44 mm long with "black spot" on back |
| May 25, 1992 | 1 | Female with large oocytes or attached ova, 44-48 mm long |
| June 8, 1992 | 0 | |
| June 12, 1992 | 0 | |
| July 21, 1992 | 0 | |
| October 8, 1992 | 12 | One female with about 15 oocytes or attached ova |
| October 14, 1992 | 7 | Lengths range from 22-29 mm |
| October 21, 1992 | 13 | Lengths range from 22.7-29.4 mm |
| October 21, 1992 | 13 | Lengths range from 22.7-29.4 mm |
| October 26, 1992 | 9 | One female with oocytes or attached ova; one juvenile? |
| November 4, 1992 | 7 | Lengths range from 22-27.2 mm |

| Date | Number observed | Notes[1] |
|---|---|---|
| November 10, 1992 | 0 | |
| November 17, 1992 | 0 | |
| March 3, 1993 | 0 | |
| April 13, 1993 | 0 | |
| June 8, 1993 | 0 | |
| June 23, 1993 | 8 | |
| June 30, 1993 | 2 | |
| July 9, 1993 | 5 | One female with oocytes or attached ova and one juvenile(?) not measured; others range 20-25 mm |
| July 14, 1993 | 11 | Three females with oocytes or attached ova not measured; remainder range 16-28 mm |
| July 23, 1993 | 0 | |
| August 5, 1993 | 0 | |
| August 10, 1993 | 0 | |
| August 20, 1993 | 0 | |
| August 25, 1993 | 5 | Three measured ranged 12 to 14 mm, two measured were about 25 mm |
| September 3, 1993 | 8 | |
| September 12, 1993 | 10 | Eight measured were <13 mm; two measured were about 25 mm |
| September 13, 1993 | 10 | |
| September 23, 1993 | 4 | Lengths range 17-24 mm |
| September 30, 1993 | 11 | No gravid females |
| October 8, 1993 | 1 | |
| October 13, 1993 | 2 | Each was <13 mm |
| October 22, 1993 | 1 | |
| October 28, 1993 | 3 | One of the three measured 22 mm |
| November 2, 1993 | 2 | Lengths range 20-22 mm |
| November 11, 1993 | 1 | |
| November 22, 1993 | 0 | |
| November 24, 1993 | 1 | 15 mm |
| November 30, 1993 | 2 | Each measured 23 mm |
| December 10, 1993 | 2 | One measured 18 mm |
| December 15, 1993 | 2 | |

| Date | Number observed | Notes[1] |
|---|---|---|
| February 14, 1994 | 0 | |
| July 21, 1994 | 0 | |
| June 4, 1996 | 5 | In window where water monitoring probes are located |
| July 12, 1996 | 5 | Observed from foot of entrance slope to window where water monitoring probes are located |
| July, 1996 | 14 | One shrimp had “at least three eggs” according to Warren Campbell and students from University of Alabama, Huntsville |
| November 11, 1996 | 1 | At foot of entrance slope; unknown sex |
| June 12, 1997 | 1 | Unknown sex |
| July 14, 1997 | 0 | |
| July 31, 1997 | 12 | Three females with oocytes or attached ova |
| August 7, 1997 | 20 | Three females with oocytes or attached ova |
| July 21, 1998 | 0 | Water very low, restricted to isolated pools |
| August 14, 1998 | 0 | |
| August 18, 1998 | 80 | Observed throughout the cave during low water; 18 shrimp had oocytes or attached ova; 85 minutes collecting time |
| October 15, 1998 | 17 | Observed throughout the cave; three had oocytes or attached ova and one was small enough to be considered a juvenile. |
| November 10, 1998 | 0 | |
| December 16, 1998 | 9 | Water level up from November sample but not sumped-no gravid females observed. |
| January 11, 1999 | 0 | No shrimp observed; cave passage sumped |
| February 17, 1999 | 0 | No shrimp observed; cave passage sumped |
| March 10, 1999 | 0 | No shrimp observed; cave passage sumped |
| April 27, 1999 | 0 | No shrimp observed; cave passage sumped |
| May 7, 1999 | 0 | No shrimp observed; cave passage sumped; 2.5-inch rain caused turbid conditions in cave |
| May 24, 1999 | 0 | |
| June 16, 1999 | 0 | |
| July 8, 1999 | 20 | Observed throughout the cave, though effort was hampered by presence of cold water up to 4 feet deep in the shrimp room. No gravid females observed. |
| August 17, 1999 | 112 | Observed throughout cave-10 females with oocytes or attached ova. |
| September 23, 1999 | 14 | Two gravid females observed; water level very low. |
| October 26, 1999 | 4 | Restricted to shrimp window. |

| Date | Number observed | Notes[1] |
|---|---|---|
| November 15, 1999 | 3 | Very low water. |
| December 15, 1999 | 4 | All in shrimp window, 1 with unknown number of oocytes or attached ova. |
| January 18, 2000 | 3 | Water unseasonably low; no gravid females observed. |
| February 15, 2000 | 0 | |
| March 21, 2000 | 0 | |
| April 15, 2000 | 0 | |
| May 11, 2000 | 0 | |
| June 12, 2000 | 40 | No shrimp with oocytes or attached ova. |
| July 19, 2000 | 40 | One shrimp with unknown number of oocytes or attached ova. |
| August 22, 2000 | 26 | Five shrimp with unknown number of oocytes or attached ova; very low water level; one deceased raccoon (*Procyon lotor*). |
| September 26, 2000 | 2 | Water levels still exceedingly low; both shrimp observed had oocytes or attached ova. |
| October 31, 2000 | 27 | Eight with oocytes or attached ova. |
| November 14, 2000 | 9 | One with oocytes or attached ova. |
| December 20, 2000 | 0 | About 2' airspace, cave not searched past entrance slope. |
| January 18, 2001 | 5 | Five shrimp observed; water level down drastically from December. |
| February 14, 2001 | 0 | No shrimp; cave sumped |
| March 20, 2001 | 0 | High water; no shrimp observed |
| April 12, 2001 | 0 | High water; no shrimp observed |
| May 17, 2001 | 1 | Cave near sumped; one cave shrimp observed at foot of entrance slope |
| June 11, 2001 | 0 | No counts made due to high water |
| July 24, 2001 | 10 | 10 shrimp observed, though water level relatively high; observed by R. Blackwood, K. Roe, and B. Kuhajda; no shrimp with oocytes or attached ova; four collected for DNA study |
| August 23, 2001 | 13 | 13 shrimp observed, one with about 10 oocytes or attached ova; water relatively high for the season |
| September 27, 2001 | 27 | Two shrimp with oocytes or attached ova; 46 crayfish and 42 southern cavefish observed in one-hour sample |
| October 30, 2001 | 0 | No shrimp observed |
| November 28, 2001 | 1 | No ova observed, 2/3 of cave observed |
| December 20, 2001 | 0 | Cave sumped; no shrimp observed at foot of entrance slope |
| January 17, 2002 | 0 | Cave sumped; no shrimp observed at foot of entrance slope |
| February 13, 2002 | 0 | Cave sumped; no shrimp observed at foot of entrance slope |

| Date | Number observed | Notes[1] |
|---|---|---|
| March 25, 2002 | 0 | Cave sumped; no shrimp observed at foot of entrance slope |
| April 15, 2002 | 0 | Cave sumped; no shrimp observed at foot of entrance slope |
| May 21, 2002 | 0 | Cave sumped; no shrimp observed at foot of entrance slope |
| June 14, 2002 | 6 | Observed from foot of entrance slope to opening to shrimp room; all with oocytes or attached ova |
| July 25, 2002 | 7 | Seven shrimp observed, none with oocytes or attached ova; water lower than June visit |
| August 21, 2002 | 5 | Five shrimp observed |
| September 18, 2002 | 5 | Five shrimp observed, none with oocytes or attached ova; water low, and generally covered in a fine film of flocculents |
| October 28, 2002 | 11 | Eleven shrimp observed in about 20 minutes; about half with oocytes or attached ova |
| November 20, 2002 | 0 | Water level higher than October; observed 15 minutes at foot of entrance slope |
| December 18, 2002 | 0 | Cave sumped |
| January 23, 2003 | 0 | Cave sumped |
| February 26, 2003 | 0 | Cave sumped |
| March 25, 2003 | 0 | Cave sumped |
| April 24, 2003 | 0 | Cave sumped |
| May 28, 2003 | 0 | Cave sumped |
| June 24, 2003 | 0 | Cave sumped |
| July 24, 2003 | 0 | Water level near ceiling of cave at entrance to shrimp room |
| August 8, 2003 | 0 | Water level only slightly lower than July |
| September 24, 2003 | 3 | Water level low enough to access rear of cave; no shrimp with oocytes or attached ova observed |
| October 15, 2003 | 1 | One cave shrimp observed, also 19 crayfish and 10 cave fish; no oocytes or attached ova |
| November 20, 2003 | 0 | No shrimp observed; isolated pools |
| December 23, 2003 | 0 | No shrimp observed; cave passage nearly sumped |
| January 22, 2004 | 0 | No shrimp observed; cave passage nearly sumped |
| February 19, 2004 | 0 | No shrimp observed; cave passage sumped |
| March 19, 2004 | 0 | No shrimp observed; cave passage sumped |
| April 22, 2004 | 0 | No shrimp observed |
| May 22, 2004 | 0 | No shrimp observed |
| June 16, 2004 | 1 | One cave shrimp observed along with three crayfish |

| Date | Number observed | Notes[1] |
|---|---|---|
| July 27, 2004 | 10 | Ten shrimp observed along with 15 southern cavefish and 34 crayfish |
| August 2004 | 0 | No observation |
| September 21, 2004 | 0 | No shrimp observed; cave passage sumped |
| October 27, 2004 | 0 | No shrimp observed; cave passage sumped |
| November 23, 2004 | 0 | No shrimp observed; cave passage sumped |
| December 21, 2004 | 0 | No shrimp observed; cave passage sumped |
| January 21, 2005 | 0 | No shrimp observed; cave passage sumped |
| February 24, 2005 | 0 | No shrimp observed; cave passage sumped |
| March 24, 2005 | 0 | No shrimp observed; cave passage sumped |
| April 26, 2005 | 0 | No shrimp observed; cave passage sumped |
| May 2005 | 0 | Water level much lower, but no shrimp observed |
| June 21, 2005 | 30 | Six with oocytes or attached ova |
| July 21, 2005 | 0 | Water low; crayfish observed |
| August 17, 2005 | 10 | One with oocytes or attached ova; water reduced to isolated pools |
| September 20, 2005 | 15 | Five with oocytes or attached ova; water reduced to isolated pools; sampled with Bryan Phillips of RSA |
| October 12, 2005 | 12 | Four with oocytes or attached ova in 30 minutes sampling time; low water level |
| November 16, 2005 | 1 | Tiny, perhaps newly hatched; 15 minutes sampling time |
| December 15, 2005 | 0 | Cave sumped |
| January 18, 2006 | 0 | Cave sumped |
| February 16, 2006 | 0 | Cave sumped |
| March 2006 | 0 | Cave sumped |
| April 19, 2006 | 0 | Water level almost to cave roof |
| May 11, 2006 | 0 | Cave sumped |
| June 28, 2006 | 19 | Three with oocytes or attached ova; 45 minutes sampling time; sampled with Bryan Phillips of Redstone Arsenal |
| July 18, 2006 | 22 | None with visible oocytes or attached ova; 45 minutes sampling time; sampled with Sydney DeJarnette |
| August 23, 2006 | 5 | Possibly one with oocytes or attached ova; 20 minutes sampling time; water extremely low due to drought |
| September 20, 2006 | 1 | Very low water due to drought; 15 minutes of sampling time; no shrimp with oocytes or attached ova |
| October 16, 2006 | 1 | Very low water due to drought, 15 minutes of sampling time; no shrimp with oocytes or attached ova |
| November 14, 2006 | 1 | Very low water due to drought, 30 minutes of sampling time; no shrimp with oocytes or attached ova |

| Date | Number observed | Notes[1] |
|---|---|---|
| December 19, 2006 | 2 | Water level still low but higher than November; 30 minutes sampling time; no shrimp with oocytes or attached ova |
| January 25, 2007 | 0 | Water level too high for access; no observations of shrimp attempted |
| February 14, 2007 | 0 | Water level too high for access; no observations of shrimp attempted |
| March 12, 2007 | 0 | Water level too high for access; no observations of shrimp attempted |
| April 16, 2007 | 0 | Water level too high for access; no observations of shrimp attempted |
| May 10, 2007 | 2 | Water level still higher than optimum but accessible; 15 minutes of sampling time; no shrimp with oocytes or attached ova |
| June 28, 2007 | 7 | Water level low; 15 minutes sampling time; 1 shrimp with oocytes or attached ova |
| July 26, 2007 | 0 | Water level low; 15 minutes sampling time |
| August 23, 2007 | 2 | Water level low; 20 minutes sampling time; no shrimp with oocytes or attached ova |
| September 18, 2007 | 0 | Water level extremely low with only a few extremely isolated pools 1-3 inches in depth; 25 minutes sampling time |
| October 17, 2007 | 0 | Water level extremely low, with only water available in shrimp window; 10 minutes sampling time |
| November 14, 2007 | 1 | Water level extremely low, with only water available in shrimp window; 10 minutes sampling time |
| December 11, 2007 | 0 | Water level extremely low, with only water available in shrimp window; 10 minutes sampling time |
| January 15, 2008 | 0 | 25 minutes sampling time |
| February 21, 2008 | 0 | Cave sumped; no observation attempted beyond foot of entrance slope |
| March 18, 2008 | 0 | Cave sumped; no observation attempted beyond foot of entrance slope |
| April 16, 2008 | 0 | Cave sumped; no observation attempted beyond foot of entrance slope |
| May 15, 2008 | 0 | Cave sumped; no observation attempted beyond foot of entrance slope |
| June 17, 2008 | 1 | Water 2’ deep and still; clouded upon disturbance; no observable oocytes or attached ova;45 minutes sampling time |
| July 24, 2008 | 1 | Observed in shrimp window; no observable oocytes or attached ova; 45 minutes sampling time |
| August 13, 2008 | 0 | May be first August sample with no shrimp observations; likely due to drought; 45 minutes sampling time |
| September 17, 2008 | 2 | No observable oocytes or attached ova; 30 minutes sampling time |

[1]- measurements=total length including rostrum

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