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WATER QUALITY AND BIOLOGICAL MONITORING IN BOBCAT AND MATTHEWS CAVES, REDSTONE ARSENAL, ALABAMA, 1990-2011

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By

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WATER QUALITY AND BIOLOGICAL MONITORING IN BOBCAT AND MATTHEWS CAVES, REDSTONE ARSENAL, ALABAMA, 1990-2011

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ABSTRACT

The Geological Survey of Alabama has conducted biological and water-quality monitoring studies of Bobcat and Matthews Caves and other caves on and near Redstone Arsenal since 1990. This report summarizes data collected during the current study period, October 2010 through September 2011, as well as a summary of water quality and shrimp population monitoring since 1990. Emphasis of the study has been to monitor the Alabama cave shrimp, which is listed as an endangered species under the Endangered Species Act and is found on Redstone Arsenal. In addition to monitoring the cave shrimp population by recording number of individuals, number of gravid individuals, and other noteworthy items relating to the shrimp, water-quality data is also collected in both Bobcat and Matthews Caves. Bobcat and Matthews Caves were visited monthly during this study period for water quality and biological monitoring. Cave shrimp were observed during October (one shrimp), June (two shrimp) and July (three shrimp, all with oocytes or attached ova). For the fourth consecutive August, no shrimp were observed during the month. Water-quality sampling indicated steady conditions in Bobcat Cave with no significant variation in dissolved solids, pH, and the nutrient condition compared to previous years. Water quality in Matthews Cave continues to show the effects of urban contaminant runoff. Concentrations of chloride, sulfate, and nitrate continue to be elevated over Bobcat Cave and the median yearly values for chloride and sulfate are trending upward. Detection percentage for cadmium and lead increased in both caves from last year while declining somewhat for chromium.

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 and was subsequently reported from Bobcat Cave on the U.S. Army's Redstone Arsenal (RSA) in southwest Madison County and in a series of three hydrologically connected caves in southeast Madison County (Rheams and others, 1994).

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, 1992; Campbell and others, 1996; McGregor and O'Neil, 1996, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2008, 2010; McGregor, O'Neil, and Campbell, 1997, 1999; McGregor, O'Neil, and Gillett, 2005; McGregor, O'Neil, and Wynn, 2008, 2009). These studies enhanced 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 four publications (Burnett and others, 2003; McGregor and others, 1994; McGregor and others, 2003; McGregor and others, 1997; Rheams and others, 1994). Another population of cave shrimp is known from Colbert County, approximately 70 miles to the west of RSA and a cave shrimp was recently collected in Key Cave, Lauderdale County. Morphological differences between these new populations and the Alabama cave shrimp suggest the need for a systematic revision of the genus.

In 2010, the Geological Survey of Alabama (GSA) was contracted by RSA to continue monitoring the Alabama cave shrimp in Bobcat Cave, to report on its life history and population trends, and to monitor water-quality and water-level trends. 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 and Shannon Allen of the Cultural and Environmental Resources Directorate coordinated access to Bobcat Cave and resolved other logistical issues throughout the year. Eric Diaz 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. Anne Wynn, Brett Smith, Cal Johnson and Tom Shepard 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. 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, 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. Groundwater 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 ultimately controls the direction of groundwater flow in the study area. The Tennessee River, which forms the southern boundary of Madison County, is the dominant surface-water feature. Throughout Madison County, all surface-water systems flow in a general southerly direction and eventually discharge into the Tennessee River.

METHODS

Chemical analyses of water samples (table 1) 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 (ADEM, 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 Model CN-70 chlorine test kit. A collected sample was inoculated with a standard reagent powder pillow, allowed to stand for three minutes for the reaction to occur, then compared against a stream blank

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

Parameter	Units [1]	Lower limit of detection	Method [2]
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 as $CaCO_3$	mg/L	3	Colorimetric, EPA 310.2
Specific conductance	μS/cm²	1	Electrometric, field
Total dissolved solids	mg/L	10	Gravimetric, USGS I-1750-85
Hardness as $CaCO_3$	mg/L	1	Calculated, USGS I-1340-85
Sulfate	mg/L	0.08	Ion chromatography, EPA 300.0
Chloride	mg/L	0.03	Ion chromatography, EPA 300.0
Bromide	mg/L	0.05	Ion chromatography, EPA 300.0
Fluoride	mg/L	0.02	Ion chromatography, USGS I-2057-85
Silica	mg/L	0.06	ICP, EPA 200.7
Bicarbonate	mg/L	3	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	0.07	Colorimetric, EPA 351.2
Nitrite as N	mg/L	0.006	Ion chromatography, EPA 300.0
Nitrate as N	mg/L	0.006	Ion chromatography, EPA 300.0
Total nitrate-nitrite as N	mg/L	0.006	Ion chromatography, EPA 300.0
Total phosphorus as P	mg/L	0.010	Colorimetric, EPA 365.1
Orthophosphate as PO_4	mg/L	0.05	Ion chromatography, EPA 300.0
Arsenic	μg/L	2	Graphite-furnace atomic absorption, EPA 200.9
Barium	μg/L	1.0	ICP, EPA 200.7
Cadmium	μg/L	0.09	Graphite-furnace atomic absorption, USGS I-1137-85
Chromium	μg/L	0.8	Graphite-furnace atomic absorption, EPA 200.9
Copper	μg/L	5	ICP, EPA 200.7
Iron	μg/L	4	ICP, EPA 200.7
Lead	μg/L	0.9	Graphite-furnace atomic absorption, EPA 200.9
Lithium	μg/L	8	Graphite-furnace atomic absorption, P-E B050-5538
Manganese	μg/L	0.8	ICP, EPA 200.7
Mercury	μg/L	0.01	Cold vapor atomic fluorescence spectrometry, EPA 245.7
Molybdenum	μg/L	20	ICP, EPA 200.7
Nickel	μg/L	20	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	0.5	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 - mg/L-milligrams per liter; ug/L-micrograms per liter; uS/cm-microSiemens per centimeter; °C-degrees Celcius

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

in the standardized color-comparison wheel. An integrated grab sample of water was collected monthly at each station, and the following raw and filtered (0.45μm) individual samples were transported (in Nasco whirl-pak sterilized bags or polyethylene bottles) to the GSA geochemical laboratory for analysis: one 18-oz raw water bag, one 4-oz filtered-chilled bag (4°C) for anions and alkalinity, one 4-oz filtered-acidified (pH <2.0 with sulfuric acid) bag for total dissolved phosphorus and ammonia analysis, one filtered-acidified (pH <2.0 with nitric acid) sample in a white polyethylene bottle for analysis of metals, one raw sample in an amber glass bottle for total organic carbon analysis, one raw sample in a small clear plastic bottle for mercury analysis, and one raw-acidified (pH<2.0 with surfuric acid) for analysis of chemical oxygen demand (COD) and total Kjeldahl nitrogen (TKN).

Biological monitoring consisted of monthly visual observations of the aquatic environment in Bobcat Cave when water levels permitted access, and recording information including number of cave shrimp 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 depending on the depth of water in Bobcat Cave, with a mean observation time of 45 minutes. No shrimp were handled to avoid physically damaging or unnecessarily stressing individuals. Similar observations have resulted from many sampling efforts varying in intensity and frequency since November 1990. The current sampling effort is intended to provide a general monitoring tool for the determination of the relative occurrence of the population over time when compared to information gathered during previous studies.

RESULTS AND DISCUSSION

WATER QUALITY

Twelve sets of water samples each were collected from Bobcat and Matthews Caves from October 2010 through September 2011 (appendix A) and analyzed for the constituents listed in table 1. Water in Bobcat Cave generally had slightly higher specific conductance, and hence higher dissolved solids content compared to Matthews Cave (fig. 1) in the earlier years of study

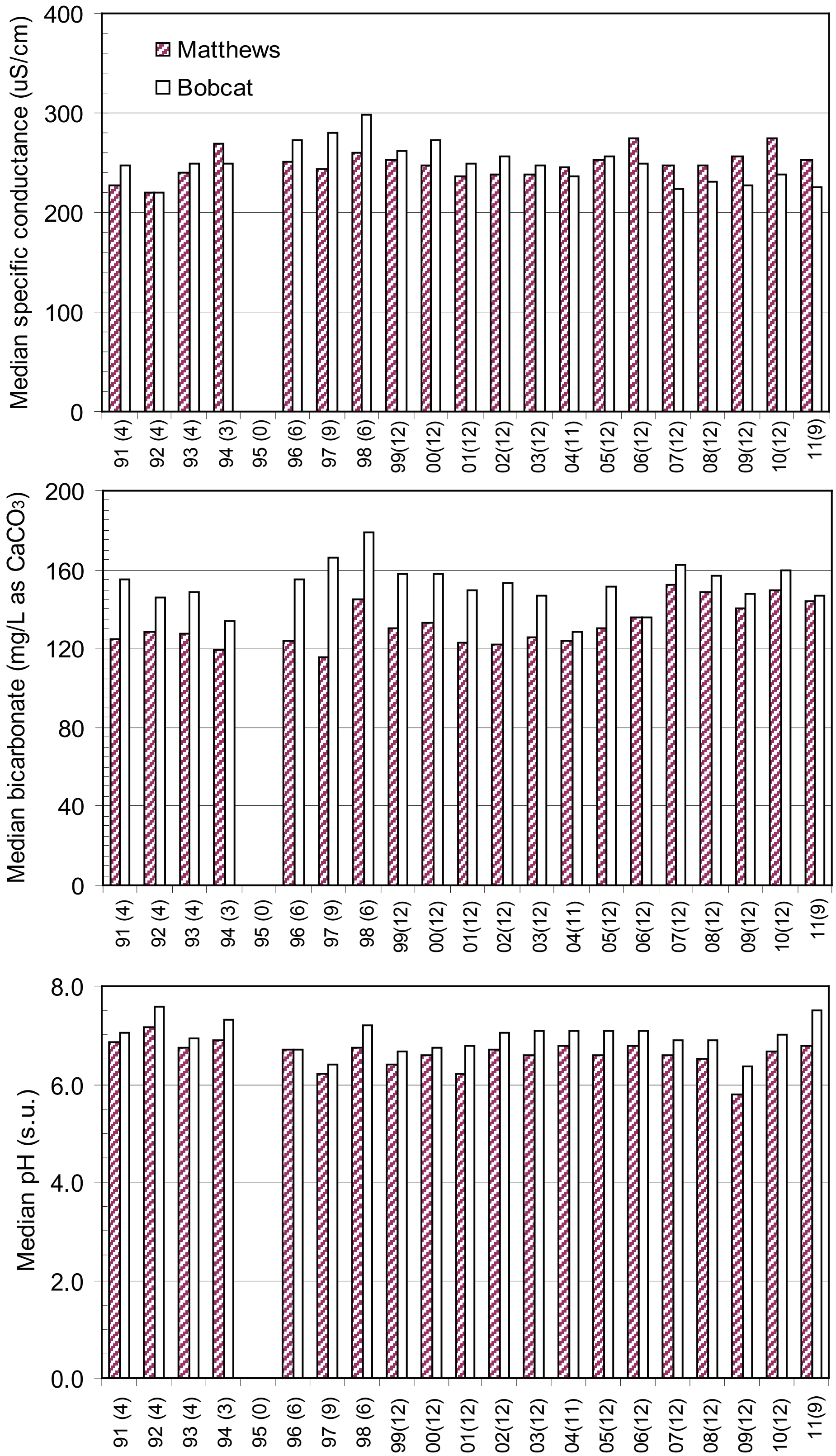

Figure 1. Plots of yearly median specific conductance, bicarbonate, and pH in Bobcat and Matthews Caves, 1991-2011. The number of samples collected each year is shown in parentheses.

but since 2006 median yearly specific conductance in Matthews has been slightly higher and may be due to the increasing concentration of contaminants in urban runoff. Other water-quality constituents that are indicators of contamination, such as chloride, nitrate, and some trace metals, enter the groundwater in both caves either through surface runoff directly into the cave or from deeper groundwater 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 groundwater for both bicarbonate and calcium. Bicarbonate in 2010-11 ranged from 139 to 182 mg/L with a median of 153 mg/L, which was essentially equal to the preceding year in Bobcat Cave. Median bicarbonate in Matthews was 148 mg/L, and ranged from 132 to 180 mg/L and was also essentially equal to the preceding year (table 2, fig. 1). 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. 1). The pH of Bobcat Cave waters in 2010-11 ranged from 5.0 to 7.6 (median, 7.5), while pH of Matthews Cave ranged from 6.0 to 7.3 (median, 6.8) for the same period (table 2). Long-term trends of pH in both caves indicated 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. 1).

Chlorine is the most abundant of the halogens, and its compounds, comprised 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 waters, and their presence in quantity may indicate contamination. Chloride ranged from 1.37 to 2.51 mg/L (median, 1.82 mg/L) in Bobcat

Table 2. Summary water-quality data for Bobcat and Matthews Caves, October 2010 through September 2011.

Parameter	Units	LLD	Bobcat min	Bobcat max	Bobcat median	Matthews min	Matthews max	Matthews median
Temperature	°C	--	13.0	20.0	16.0	14.0	21.0	17.0
Dissolved oxygen	mg/L	0.1	6.7	9.6	7.8	6.5	10.2	8.0
Total residual chlorine	mg/L	0.02	<.02	0.12	0.03	<.02	0.10	0.03
pH	units	--	5.0	7.6	7.5	6.0	7.3	6.8
Alkalinity as $CaCO_3$	mg/L	3	114	149	126	108	148	121
Specific conductance	μS/cm	1	214	294	226	203	292	251
Total dissolved solids	mg/L	10	128	161	138	138	179	150
Hardness as $CaCO_3$	mg/L	1	111	142	122	115	150	127
Sulfate	mg/L	0.08	<.08	3.51	2.40	2.62	3.70	3.00
Chloride	mg/L	0.03	1.37	2.51	1.82	4.94	7.69	5.47
Bromide	mg/L	0.05	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	0.02	<.02	0.03	<.02	<.02	0.04	<.02
Silica	mg/L	0.06	7.20	8.21	7.64	7.58	8.59	8.16
Bicarbonate	mg/L	3	139	182	153	132	180	148
Carbonate	mg/L	1	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.02	<.02	0.3	<.02	<.02	0.20	0.03
Total Kjeldahl nitrogen	mg/L	0.07	<.07	1.3	0.4	<.07	0.82	0.44
Nitrite as N	mg/L	0.006	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	0.006	0.183	0.732	0.450	1.900	3.220	2.370
Total nitrate-nitrite as N	mg/L	0.006	0.183	2.940	0.546	1.900	3.220	2.370
Total phosphorus as P	mg/L	0.010	<.01	0.13	0.11	<.01	0.13	0.12
Orthophosphate as PO_4	mg/L	0.05	<.05	<.05	<.05	<.05	0.05	0.00
Arsenic	μg/L	2	<2	<2	<2	<2	<2	<2
Barium	μg/L	1.0	15.6	137.0	50.8	14.5	69.3	48.5
Cadmium	μg/L	0.09	<.09	0.47	<.09	<.09	0.23	0.06
Chromium	μg/L	0.8	<.8	3.3	1.4	<.8	1.4	<.8
Copper	μg/L	5	<5	13	<5	<5	<5	<5
Iron	μg/L	4	<4	62	<4	<4	9	<4
Lead	μg/L	0.9	<.9	38.0	2.0	1.1	39.2	4.4
Lithium	μg/L	8	<8	<8	<8	<8	<8	<8
Manganese	μg/L	0.8	<.8	34.2	<.8	<.8	6.0	<.8
Mercury	μg/L	0.01	<.01	<.01	<.01	<.01	<.01	<.01
Molybdenum	μg/L	20	<20	<20	<20	<20	<20	<20
Nickel	μg/L	20	<20	<20	<20	<20	<20	<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	49.0	61.9	53.2	53.4	68.3	58.6
Zinc	μg/L	4	<4	80	27	<4	359	22
Total organic carbon	mg/L	0.4	<.4	12.1	2.5	<.4	10.6	1.8
Chemical oxygen demand	mg/L	30	<30	100	51	<30	122	70

Cave and from 4.94 to 7.69 mg/L (median, 5.47 mg/L) in Matthews Cave (table 2) in 2010-11. The median concentration of chloride in Matthews Cave has consistently varied from about one and a half to two times the median chloride concentration in Bobcat Cave over the period 1991 through 2011 (fig**.** 2), indicating that water in Matthews Cave likely has a greater connectivity to polluted surface runoff and groundwater. Yearly median chloride in Matthews Cave shows a long-term increasing trend perhaps related to increasing urbanization in the recharge area.

Sulfate concentrations ranged from <0.08 to 3.51 mg/L (median, 2.40 mg/L) in Bobcat and from 2.62 to 3.70 mg/L (median, 3.00 mg/L) in Matthews (table 2) in 2010-11. Median sulfate concentrations in Bobcat were greater than Matthews Cave in the earlier years of investigation, while since 2006, median sulfate has been both increasing and greater than concentrations in Bobcat Cave. Like chloride, the long-term trend for median sulfate is increasing in Matthews Cave supporting the idea that urban runoff entering Matthews Cave is carrying an increasing amount of pollutants.

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 groundwater, 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 0.18 to 0.73 mg/L (median, 0.45 mg/L) in Bobcat and from 1.90 to 3.22 mg/L (median, 2.37 mg/L) in Matthews from 2010-11 (table 2). From 1991-2011, the median nitrate concentrations in Bobcat Cave have ranged from near 0.5 to just over 1.0 mg/L, whereas the median concentrations in Matthews Cave have ranged from near 2.5 to near 3.5 mg/L (fig. 2). Ammonia was detected in 9 out of 12 samples from Bobcat Cave and in 7 out of 12 samples from Matthews Cave in 2010-11 (appendix A). Median phosphorus concentrations during 2010-11 were elevated in each cave over previous years with total dissolved phosphorus ranging from <.01 to 0.13 mg/L in Bobcat Cave (median, 0.11 mg/L) and from <.01 to 0.13 mg/L in Matthews Cave (median, 0.12 mg/L).

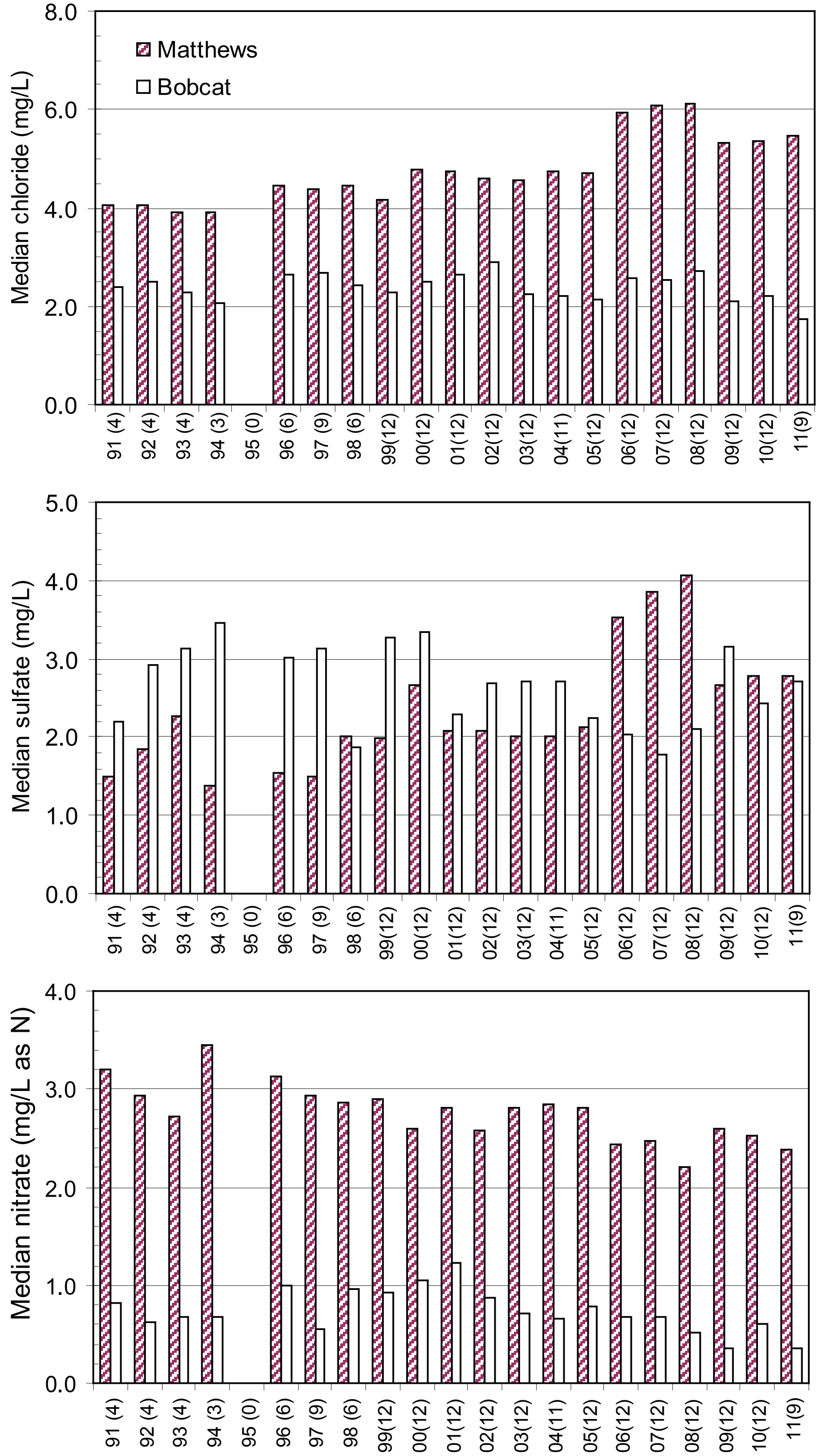

Figure 2. Plots of yearly median chloride, sulfate, and nitrate in Bobcat and Matthews Caves, 1991-2011. The number of samples collected is shown in parentheses.

In natural waters unaffected by pollution in the southeast, trace metals occur in low concentrations, generally <1.0 μg/L. Elevated trace metal concentrations may indicate the presence of a pollution source or a nearby ore deposit. Cadmium was detected in 5 of 12 samples from Bobcat Cave (0.10, 0.47, 0.12, 0.15, and 0.16 μg/L) and in 6 of 12 samples from Matthews Cave (0.12, 0.12, 0.23, 0.22, 0.12, and 0.12 μg/L) in 2010-11 (appendix A). 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 1996-2011 indicate a declining trend in cadmium concentration and detections in both Bobcat and Matthews Caves (figs. 3, 4); however, cadmium detections increased substantially this last year over the previous year although concentrations were still relatively low comparatively. Cadmium detections averaged 58.3 percent for Bobcat Cave and 57.9 percent for Matthews Cave over the study period (table 3).

Chromium was detected in 9 of 12 samples from Bobcat Cave in 2010-11 (appendix) and ranged from <0.8 to 3.3 μg/L with a median of 1.4 μg/L (table 2). Chromium was detected in 3 of 12 samples from Matthews Cave ranging from <0.8 to 1.4 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 has been variable in Bobcat Cave with highs of 100, 75, and 75 percent and lows of 25, 33, and 36 percent from 1996 through 2011 (table 2, fig. 4). Chromium detections in Matthews Cave have been substantially lower with highs of 60, 67, and 67 percent and lows of 0, 0, and 8 percent. Chromium detections have averaged 58.8 percent for Bobcat Cave and 25.1 percent for Matthews Cave during the period 1996-2011 (table 3).

Lead was detected in 11 of 12 samples from Bobcat Cave in 2010-11, ranging from <0.9 to 38.0 μg/L with a median of 2.0 μg/L. Lead was detected in 12 of 12 samples from Matthews Cave, ranging from 1.1 to 39.2 μg/L with a median of 4.4 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.

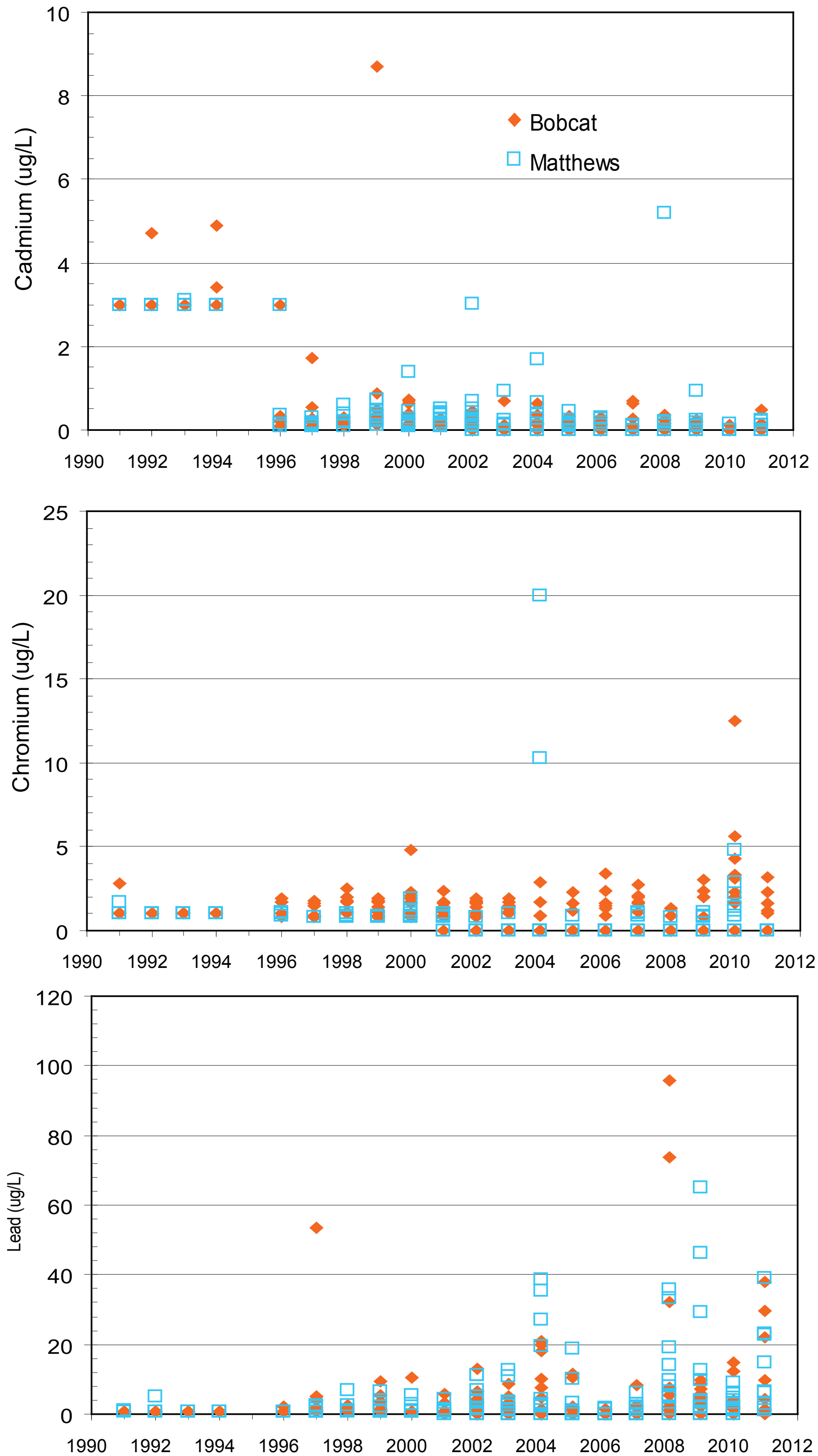

Figure 3. Selected trace metal concentrations of water from Bobcat and Matthews Caves, 1991-2011.

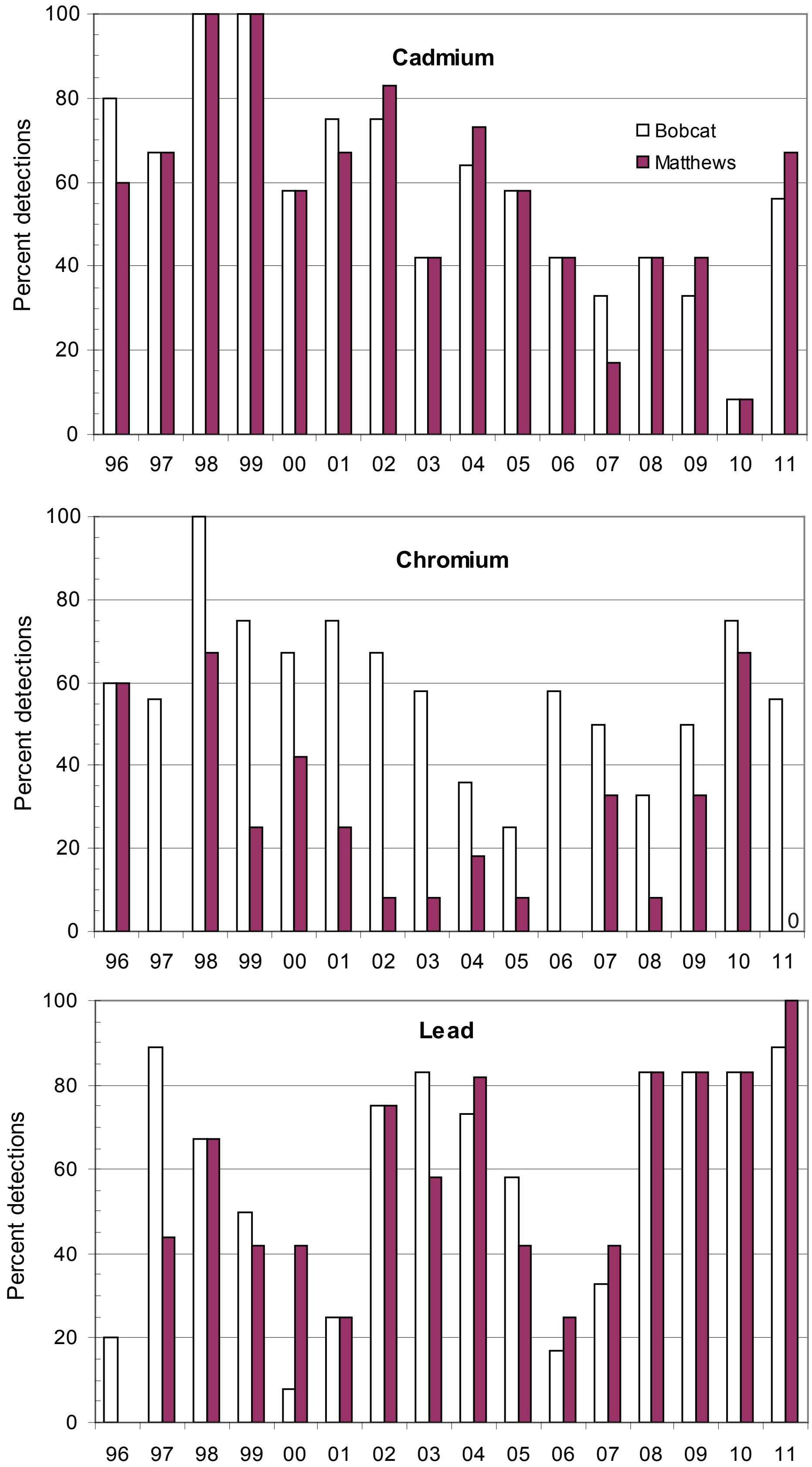

Figure 4. Yearly detection rates of cadmium, chromium, and lead in Bobcat and Matthews Caves, 1996-2011.

Table 3. Yearly detection rate (percent of samples collected) of selected trace metals in water collected from Bobcat and Matthews Caves, 1996-2011.

Year	Number of samples	Cadmium		Chromium		Lead	
		Bobcat	Matthews	Bobcat	Matthews	Bobcat	Matthews
1996	6	80	60	60	60	20	0
1997	9	67	67	56	0	89	44
1998	6	100	100	100	67	67	67
1999	12	100	100	75	25	50	42
2000	12	58	58	67	42	8	42
2001	12	75	67	75	25	25	25
2002	12	75	83	67	8	75	75
2003	12	42	42	58	8	83	58
2004	11	64	73	36	18	73	82
2005	12	58	58	25	8	58	42
2006	12	42	50	58	0	17	25
2007	12	25	17	50	33	17	25
2008	12	42	42	33	8	83	83
2009	12	33	42	50	33	83	83
2010	12	8	8	75	67	83	83
2011	9	56	67	56	0	89	100
Average		58.3	57.9	58.8	25.1	58.5	55.8

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 (table 3). Lead detections declined progressively in each succeeding year to 17 percent in 2006 but have remained high for the past few years at 83 percent in 2008, 83 percent in 2009, and 78 percent in 2010, and 89 percent through September in 2011. The yearly maximum lead values for the past decade in Bobcat Cave are elevated above the detection limit: 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, 95.8 μg/L in 2008, 9.6 μg/L in 2009, 14.8 μg/L in 2010, and 38.0 μg/L through September in 2011. Similarly, the maximum yearly lead values for Matthews Cave the past decade have also been above detection limits: 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, 35.7 μg/L in 2008, 65.2 μg/L in 2009, 9.1 μg/L in 2010, and 39.2 μg/L through September 2011. Lead detections since 1996 have averaged above 50 percent of all samples collected in each cave (table 3). There is an interesting cyclical pattern of yearly lead detection rates that appears to repeat every five to seven years (fig. 4).

Median chemical oxygen demand (COD) was slightly lower in Bobcat Cave, 51 mg/L, compared to 70 mg/L in Matthews Cave. Median total organic carbon was higher in both caves over the previous year with a median of 2.5 mg/L at Bobcat and 1.8 mg/L at Matthews 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 2011. 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) groundwater 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 5, along with daily rainfall records provided by RSA. The

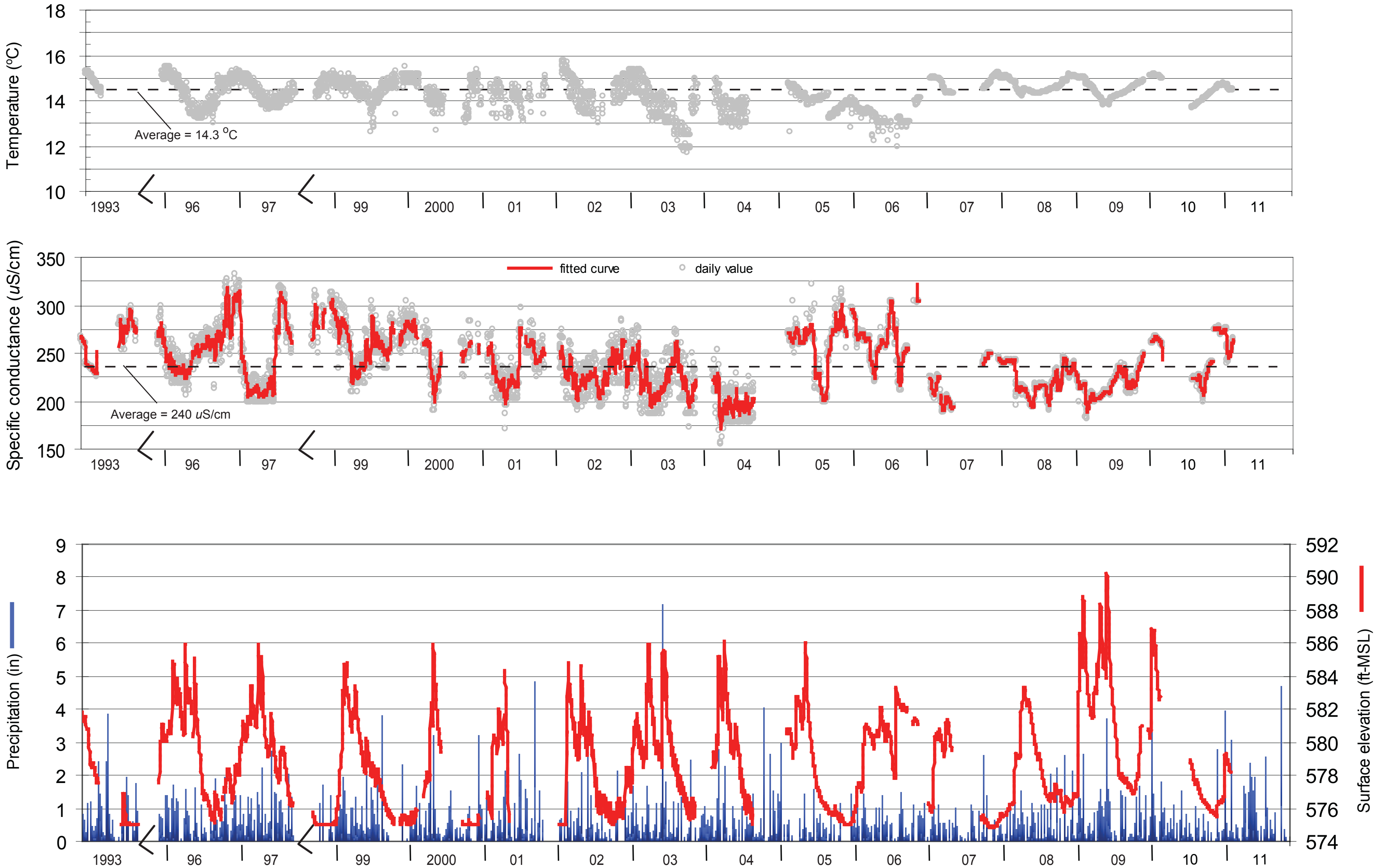

Figure 5. Daily water-quality monitoring data for Bobcat Cave, 1993-2011.

internal processor of the instrument failed in late December and was undiscovered until February when Bobcat was visited for a data download. Water levels in the cave remained too high to retrieve the monitor throughout the spring and into the summer. Once recovered, the instrument was sent for assessment and repair. It was received in mid-October and has now been placed back into service in Bobcat Cave. Due to this event we lost a significant period of data record for 2011. The rainfall station is located about seven miles to the southeast of Bobcat Cave and therefore 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 April and lowest from August through October (fig. 5). Rising groundwater during winter months increases the base level of Bobcat Cave by approximately 7 feet, from 575 ft-msl to around 582 ft-msl. Runoff associated with storm fronts can temporarily raise the surface elevation another 5 feet to a level of 586 feet (fig. 5). The maximum water surface elevation measured since 1993 was recorded on May 2, 2009, at 590.2 ft-msl, 15 feet above the minimum measurable level in Bobcat Cave. Approximately 5.9 inches of rain had fallen over the previous 3.5 days. 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 water runoff. Water is present only in isolated pools and windows at 575 feet. Water level in Bobcat Cave has averaged 578.9 ft-msl over the period 1993 through 2011.

Bobcat Cave has a very stable water temperature regime throughout the year and averaged 14.3°C from 1993-2011. Temperature generally varies 2°C throughout the year, ranging from around 13°C to slightly over 15°C (fig. 5). The highest average monthly water temperature occurs in November and December, while the lowest occurs 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 groundwater 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 groundwater from deep aquifers that contribute to the cave's water supply. Average specific conductance from 1993 through 2010 was 240 μS/cm, ranging from 155 to 333 μS/cm (fig. 5). Specific conductance spikes occurred when cave water levels 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 groundwater with a higher mineral content begins to dominate Bobcat Cave's water supply.

BIOLOGICAL MONITORING

Bobcat Cave was visited monthly from October 2010 to September 2011 (Appendix B; fig. 6). Only six shrimp were observed; one on October 19, 2010, two on June 16, 2011, and three on July 21, 2011. All three shrimp observed on July 21 had oocytes or attached ova. August generally produces the most sightings in Bobcat Cave (maximum 112 on August 17, 1999), but for the fourth consecutive August none were observed during the month and only 2 to 5 individuals were observed during August for the preceding few years. None were observed in August 2003 due to unusually high water level for that month, or in August 2004, when no observation was attempted. A multi-year drought likely affected shrimp populations, restricting them to deep groundwater or, perhaps, affecting reproduction. With a return to a normal rainfall pattern, numbers may return to previous levels in the future.

Information concerning long-term trends in the shrimp population in Bobcat Cave (1990-2011) is found in figure 6. June, July, and August are generally the months when shrimp are most prevalent and observable, each month having yielded 40 or more shrimp in one or more visits during this study. 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 of shrimp are observed during June through August is because the cave can only be visited at low water levels as occurs during those months. 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

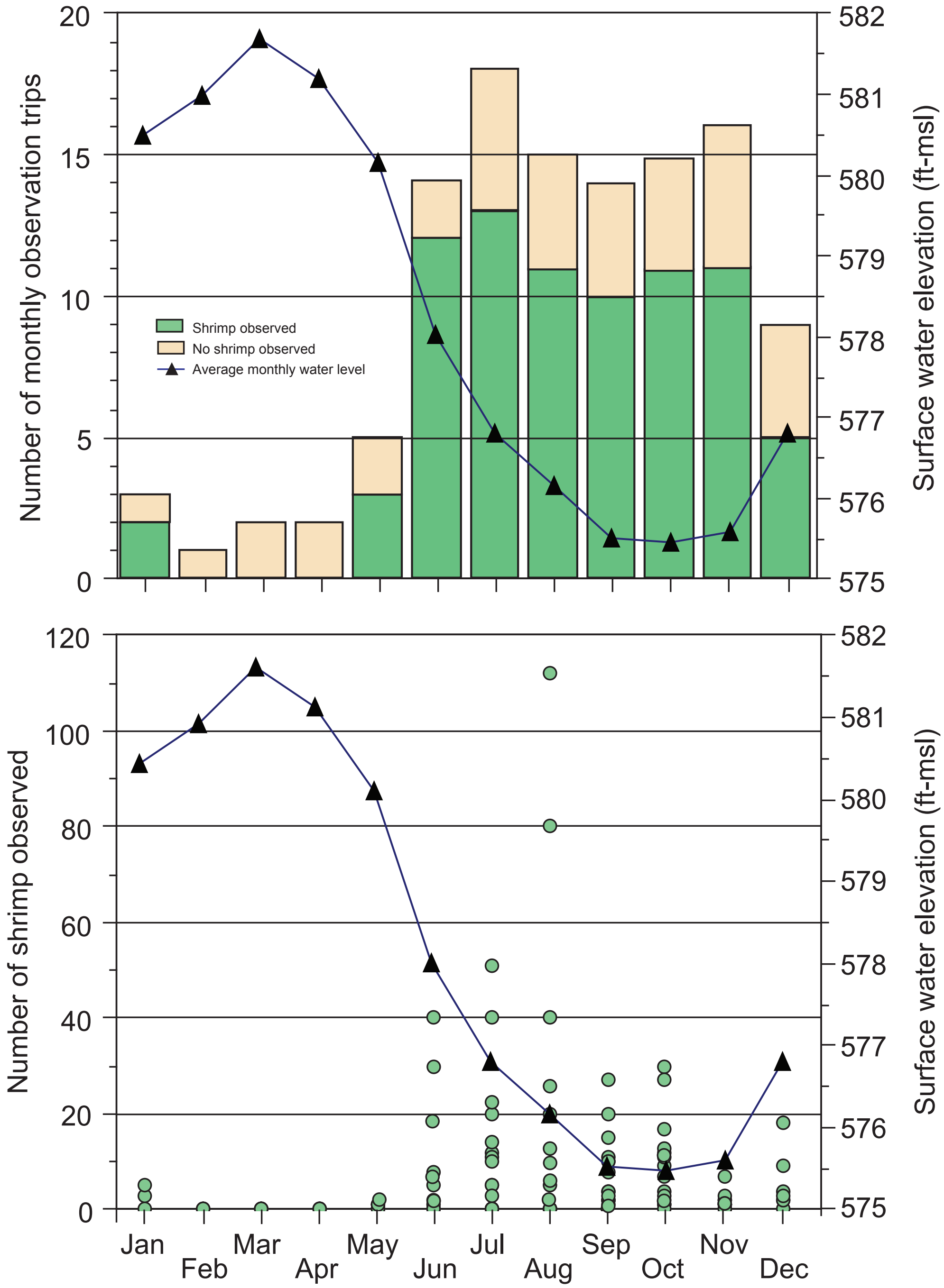

Figure 6. Shrimp observations and counts in Bobcat Cave, 1990-2011.

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 6, shrimp have been observed in almost every visit in September, probably a result of some shrimp that didn't escape to the lower level and became stranded. 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 four occasions during the collective months of May probably due to 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 further refine and 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 and cadmium, and parameters associated with urban runoff. Increasing urbanization around RSA will likely affect groundwater, which may have consequences for Bobcat Cave and the Alabama cave shrimp. We are now observing this in Matthews Cave where levels of chloride, sulfate, and nitrate are higher than those observed in Bobcat Cave and the trend of median contaminant concentration appears to be increasing over time.

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APPENDIX A

Water-quality sampling data
2010-2011

Site Date Time	Units	Bobcat 19-Oct-10 10:30	Bobcat 16-Nov-10 10:45	Bobcat 14-Dec-10 11:30	Bobcat 18-Jan-11 10:15	Bobcat 28-Feb-11 13:55	Bobcat 16-Mar-11 10:55
Temperature	°C	16	17	13	16	16	15
Dissolved oxygen	mg/L	7.4	8.2	9.4	7.6	9.6	7.9
Total residual chlorine	mg/L	0.04	0.03	<.02	<.02	<.02	0.03
pH	units	6.7	5.7	7.6	5.0	7.6	7.6
Alkalinity as $CaCO_3$	mg/L	149	146	132	116	121	115
Specific conductance	µS/cm²	294	238	231	267	220	225
Total dissolved solids	mg/L	161	156	144	129	143	128
Hardness as $CaCO_3$	mg/L	142	138	126	111	141	113
Sulfate	mg/L	0.90	1.73	2.22	2.87	2.52	3.51
Chloride	mg/L	2.39	2.05	1.86	1.58	2.13	1.44
Bromide	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Silica	mg/L	7.85	7.80	7.68	7.96	7.87	7.59
Bicarbonate	mg/L	182	178	160	141	147	140
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.03	<.02	0.03	0.03	0.04	<.02
Total Kjeldahl nitrogen	mg/L	0.18	0.17	0.35	0.63	0.59	1.27
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	0.669	0.369	0.712	0.53	0.561	0.354
Total nitrate-nitrite as N	mg/L	0.669	0.369	0.712	0.53	0.561	0.354
Total phosphorus as P	mg/L	0.02	0.10	0.12	0.13	<.01	<.01
Orthophosphate as PO_4	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Arsenic	µg/L	<2	<2	<2	<2	<2	<2
Barium	µg/L	101	57.6	18.1	41.4	46.1	15.6
Cadmium	µg/L	<.09	<.09	<.09	0.10	<.09	<.09
Chromium	µg/L	3.3	2.0	2.3	1.2	<.8	0.0
Copper	µg/L	<5	<5	<5	13	<5	<5
Iron	µg/L	<4	<4	62	10	<4	6
Lead	µg/L	1.4	1.9	2.1	1.4	1.0	1.2
Lithium	µg/L	<8	<8	<8	<8	<8	<8
Manganese	µg/L	<.8	<.8	34.2	<.8	<.8	<.8
Mercury	µg/L	<.01	<.01	<.01	<.01	<.01	<.01
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	61.9	59.8	54.8	50.1	49.0	51.1
Zinc	µg/L	24	17	<4	31	14	<4
Total organic carbon	mg/L	12.1	2.2	3.2	4.5	5.2	<.4
Chemical oxygen demand	mg/L	<30	100	60	82	52	50

Site Date Time	Units	Bobcat 21-Apr-11 11:15	Bobcat 19-May-11 13:10	Bobcat 16-Jun-11 13:30	Bobcat 21-Jul-11 10:30	Bobcat 16-Aug-11 10:30	Bobcat 21-Sep-11 11:40
Temperature	°C	16	18	20	16	20	16
Dissolved oxygen	mg/L	7.4	7.9	9.0	7.2	7.7	6.7
Total residual chlorine	mg/L	0.11	0.12	<.02	0.02	0.10	0.08
pH	units	7.3	7.6	7.6	7.5	6.8	7.5
Alkalinity as $CaCO_3$	mg/L	129	128	124	114	118	128
Specific conductance	μS/cm²	214	227	220	215	255	225
Total dissolved solids	mg/L	143	137	134	130	130	139
Hardness as $CaCO_3$	mg/L	128	121	116	116	116	124
Sulfate	mg/L	3.40	3.14	2.71	1.64	0.00	2.27
Chloride	mg/L	1.37	1.75	1.78	2.51	2.25	1.58
Bromide	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	0.03
Silica	mg/L	8.21	7.22	7.37	7.30	7.20	7.22
Bicarbonate	mg/L	157	155	151	139	144	156
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.31	<.02	0.02	0.03	0.04	0.03
Total Kjeldahl nitrogen	mg/L	<.07	0.38	0.29	0.25	0.37	0.61
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	0.183	0.195	0.313	0.732	0.596	0.333
Total nitrate-nitrite as N	mg/L	0.183	0.195	2.94	0.732	0.596	0.333
Total phosphorus as P	mg/L	0.12	0.13	0.09	0.11	0.12	0.12
Orthophosphate as PO_4	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Arsenic	μg/L	<2	<2	<2	<2	<2	<2
Barium	μg/L	104	47.1	54.4	68.6	42.1	137
Cadmium	μg/L	<.09	0.47	0.12	0.15	0.16	<.09
Chromium	μg/L	0.0	0.0	1.0	3.2	1.6	2.3
Copper	μg/L	<5	<5	<5	<5	<5	<5
Iron	μg/L	<4	<4	5	<4	<4	15
Lead	μg/L	<.9	4.3	29.6	22.1	38.0	9.9
Lithium	μg/L	<8	<8	<8	<8	<8	<8
Manganese	μg/L	<.8	<.8	<.8	<.8	<.8	1.2
Mercury	μg/L	<.01	<.01	<.01	<.01	<.01	<.01
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	60.4	53.6	52.7	50.4	50.8	55.2
Zinc	μg/L	31	28	28	41	26	80
Total organic carbon	mg/L	5.1	<.4	<.4	<.4	0.8	2.9
Chemical oxygen demand	mg/L	88	<30	<30	51	<30	43

Site Date Time	Units	Matthews 19-Oct-10 11:30	Matthews 16-Nov-10 11:35	Matthews 14-Dec-10 10:20	Matthews 18-Jan-11 10:45	Matthews 28-Feb-11 13:10	Matthews 16-Mar-11 10:10
Temperature	°C	19	16	14	14	17	17
Dissolved oxygen	mg/L	8.7	7.6	8.4	8.1	8.7	6.5
Total residual chlorine	mg/L	0.06	<.02	0.05	<.02	<.02	<.02
pH	units	7.2	6.0	6.9	6.2	7.1	6.8
Alkalinity as $CaCO_3$	mg/L	148	124	114	116	134	108
Specific conductance	µS/cm²	279	249	231	203	285	248
Total dissolved solids	mg/L	179	152	145	145	165	138
Hardness as $CaCO_3$	mg/L	150	128	120	121	141	116
Sulfate	mg/L	3.55	3.70	2.97	3.07	3.14	2.72
Chloride	mg/L	6.75	5.13	6.89	5.45	5.94	4.94
Bromide	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	0.04
Silica	mg/L	8.28	8.04	8.29	8.59	8.58	8.53
Bicarbonate	mg/L	180	151	139	141	163	132
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	<.02	<.02	0.02	<.02	0.05	0.20
Total Kjeldahl nitrogen	mg/L	0.28	0.13	0.51	0.66	0.54	0.82
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	2.38	1.9	2.19	2.12	2.36	2.38
Total nitrate-nitrite as N	mg/L	2.38	1.9	2.19	2.12	2.36	2.38
Total phosphorus as P	mg/L	<.01	0.11	0.12	0.13	<.01	<.01
Orthophosphate as PO_4	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Arsenic	µg/L	<2	<2	<2	<2	<2	<2
Barium	µg/L	67.6	59.2	15.4	50.9	49.9	15.4
Cadmium	µg/L	<.09	<.09	<.09	0.12	<.09	<.09
Chromium	µg/L	0.9	0.9	1.4	<.8	<.8	<.8
Copper	µg/L	<5	<5	<5	<5	<5	<5
Iron	µg/L	<4	<4	9	<4	<4	<4
Lead	µg/L	1.2	1.6	1.9	2.8	6.1	1.1
Lithium	µg/L	<8	<8	<8	<8	<8	<8
Manganese	µg/L	<.8	<.8	6	<.8	<.8	<.8
Mercury	µg/L	<.01	<.01	<.01	<.01	<.01	<.01
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	68.3	61.6	55.1	55.9	64.3	53.4
Zinc	µg/L	22	22	6	23	24	7
Total organic carbon	mg/L	10.6	1.7	<.4	1.8	6.4	2.7
Chemical oxygen demand	mg/L	79	122	62	113	77	42

Site Date Time	Units	Matthews 21-Apr-11 10:15	Matthews 19-May-11 12:10	Matthews 16-Jun-11 11:40	Matthews 21-Jul-11 9:40	Matthews 16-Aug-11 11:55	Matthews 21-Sep-11 10:20
Temperature	°C	17	21	21	19	16	18
Dissolved oxygen	mg/L	7.3	8.1	10.2	6.7	7.8	7.8
Total residual chlorine	mg/L	0.10	0.05	<.02	0.03	0.06	0.03
pH	units	6.4	6.8	6.7	6.7	7.3	6.8
Alkalinity as $CaCO_3$	mg/L	110	118	129	127	118	124
Specific conductance	µS/cm²	226	253	292	260	232	266
Total dissolved solids	mg/L	140	148	165	160	147	153
Hardness as $CaCO_3$	mg/L	115	121	136	137	125	131
Sulfate	mg/L	2.66	2.62	2.68	3.03	2.77	3.10
Chloride	mg/L	5.20	5.83	7.69	5.48	5.06	5.25
Bromide	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	0.04	<.02	<.02	<.02	<.02	<.02
Silica	mg/L	8.17	7.58	7.85	7.76	7.90	8.14
Bicarbonate	mg/L	134	144	157	155	144	151
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.19	<.02	<.02	0.15	0.03	0.03
Total Kjeldahl nitrogen	mg/L	<.07	0.38	0.51	0.23	0.36	0.49
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	2.58	2.94	3.22	2.78	2.13	2.14
Total nitrate-nitrite as N	mg/L	2.58	2.94	3.22	2.78	2.13	2.15
Total phosphorus as P	mg/L	0.12	0.12	0.09	0.11	0.12	0.12
Orthophosphate as PO_4	mg/L	<.05	<.05	0.05	<.05	<.05	<.05
Arsenic	µg/L	<2	<2	<2	<2	<2	<2
Barium	µg/L	14.5	47.1	69.3	36.4	41.3	51.4
Cadmium	µg/L	<.09	0.12	0.12	0.23	0.22	0.12
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	1.7	6.4	14.7	39.2	22.6	23.2
Lithium	µg/L	<8	<8	<8	<8	<8	<8
Manganese	µg/L	<.8	<.8	<.8	<.8	<.8	<.8
Mercury	µg/L	<.01	<.01	<.01	<.01	<.01	<.01
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	53.9	55.6	62.1	60.8	56.7	60.5
Zinc	µg/L	10	19	42	51	359	<4
Total organic carbon	mg/L	<.4	2.2	0.7	<.4	1.8	5.1
Chemical oxygen demand	mg/L	101	<30	36	81	<30	<30

APPENDIX B

Chronological list of recent Alabama cave shrimp observations in Bobcat Cave
November 1990-September 2011

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	

Date	Number observed	Notes[1]
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
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

Date	Number observed	Notes[1]
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	
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	

Date	Number observed	Notes[1]
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.
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.

Date	Number observed	Notes[1]
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 feet of 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
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

Date	Number observed	Notes[1]
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

Date	Number observed	Notes[1]
June 16, 2004	1	One cave shrimp observed along with three crayfish
July 27, 2004	10	Ten shrimp observed along with 15 southern cavefish and 34 crayfish
August 1, 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 1, 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 1, 2006	0	Cave sumped
April 19, 2006	0	Water level almost to cave roof
May 11, 2006	0	Cave sumped

Date	Number observed	Notes[1]
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
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

Date	Number observed	Notes[1]
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 feet 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
October 15, 2008	0	No shrimp seen; water surface covered by thin film, moderately low level; 15 minutes sampling time
November 12, 2008	1	Only shrimp observed was in shrimp window; low water level
December 10, 2008	0	Heavy rain the night before caused the water level to rise to about 1.5 feet depth and water was clouded by runoff, therefore if shrimp were present they were obscured
January 28, 2009	0	Water in Bobcat Cave high; no access past entrance slope
February 25, 2009	0	Water in Bobcat Cave high; no access past entrance slope
March 31, 2009	0	Water in Bobcat Cave very high, past the hand line used for secure access.
April 22, 2009	0	Water in Bobcat Cave still high; looked for cave shrimp at foot of entrance slope
May 11, 2009	0	Water in Bobcat Cave higher than during April visit; access to cave limited; no cave shrimp seen in cave entrance
June 23, 2009	0	Water in Bobcat Cave still high and cave still mostly inaccessible; no shrimp observed due to water level
July 29, 2009	0	Water level in Bobcat lower but still basically waist deep throughout the cave and with film of sediment on surface; searched cave anyway
August 25, 2009	0	Water level in cave higher than normal for this time of year; 45 minutes spent searching pools for shrimp

Date	Number observed	Notes[1]
September 21, 2009	0	Two person hours spent searching entire cave; water level low, but higher than normal for September; thin film of sediment on surface hampered viewing
October 20, 2009	0	No shrimp observed; water level higher than during September visit
November 23, 2009	0	No shrimp observed at foot of entrance slope
December 16, 2009	0	No shrimp observed at foot of entrance slope
January 19, 2010	0	No shrimp observed at foot of entrance slope
February 22, 2010	0	No shrimp observed at foot of entrance slope
March 23, 2010	0	No shrimp observed at foot of entrance slope
April 13, 2010	0	No shrimp observed at foot of entrance slope
May 11, 2010	0	No shrimp observed at foot of entrance slope
June 16, 2010	1	One shrimp with oocytes or attached ova in shrimp window
July 22, 2010	6	Low water, with thin film of sediment on surface of water; no shrimp with oocytes or attached ova; 80 minutes observation
August 16, 2010	0	No shrimp observed in 15-minute sampling time; only water is in shrimp window
September 22, 2010	0	No shrimp observed in 15-minute sampling time; water level very low, only in shrimp window
October 19, 2010	1	Water level very low, reduced to area around monitor probe
November 16, 2010	0	Water level slightly higher than October visit
December 14, 2010	0	Water level slightly higher than November visit
January 18, 2011	0	Cave sumped
February 28, 2011	0	Cave sumped
March 16, 2011	0	Cave sumped
April 21, 2011	0	Cave sumped
May 19, 2011	0	Water level lower than April but still high; observation limited to the foot of the entrance slope
June 16, 2011	2	None with oocytes or attached ova; one hour sampling time

Date	Number observed	Notes[1]
July 21, 2011	3	All with oocytes or attached ova; 30 minutes sampling time
August 16, 2011	0	1.5 hours sampling time
September 21, 2011	0	0 shrimp observed in 30 minutes sampling time

[1]- measurements=total length including rostrum

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