GEOLOGICAL SURVEY OF ALABAMA

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WATER QUALITY AND BIOLOGICAL MONITORING IN BOBCAT AND MATTHEWS CAVES, REDSTONE ARSENAL, ALABAMA, 1990-2006
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By

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with field investigations and geochemical analyses by
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ABSTRACT

Basic water chemistry from October 2005 through September 2006 remained relatively unchanged in Bobcat Cave compared to previous years. Matthews Cave had slightly increased levels of chloride and sulfate, parameters typically associated with increased urbanization in a watershed. The maximum concentrations of cadmium, chromium, and lead continued to decline in 2005 and 2006 from higher levels observed in earlier years. The yearly rate of detection for these three trace metals also declined this year from previous years. Bobcat Cave was visited on 12 occasions this year and cave shrimp were observed during six of these visits. Eight of 50 shrimp observed had oocytes or attached ova. The highest number of shrimp observed this year was 22 on July 18, 2006. August generally produces the most sightings of cave shrimp in Bobcat Cave, but this year only five (1 with attached ova) were observed in that month. This was probably because shrimp had migrated to lower cave levels due to extremely low water levels during this year's summer drought.

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, 1994; Campbell and others, 1996; McGregor and O'Neil, 1996, 2000, 2001, 2002, 2003, 2004; 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). Another population of cave shrimp is known from Colbert County, approximately 70 miles to the west of RSA. Morphological differences between this new population and the Alabama cave shrimp suggest the need for a systematic revision of the genus.

In 2005, 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 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. Marlon Cook, Neil Moss, Arthur McLin, Tom Shepard, and 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. 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 Zeirdt 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. 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 ultimately controls the direction of ground-water flow in the study area. The Tennessee River, which forms the southern boundary of Madison County, is the dominant surface-water feature in the area. 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 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 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 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 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-untreated bag, one 4-oz filtered-chilled bag (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, and one filtered-acidified (pH <2.0 with sulfuric acid) sample in a brown polyethylene bottle.

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 varying in intensity and frequency since November 1990. 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 each were collected from Bobcat and Matthews Caves from October 2005 through September 2006 (appendix). 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. 1). 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 2005-06 ranged from 111 to 179 mg/L with a median of 135 mg/L, which was lower than the preceding year in Bobcat Cave, while the median bicarbonate in Matthews at 135 mg/L, and ranging from 111 to 166 mg/L, was slightly higher than the preceding year (table 1; 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 144 mg/L in 1998 (fig. 1). The pH of Bobcat Cave waters in 2005-06 ranged from 6.2 to 7.5 (median, 6.8), while pH of Matthews Cave ranged from 5.8 to 7.6 (median, 6.7) for the same period (table 1). 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,

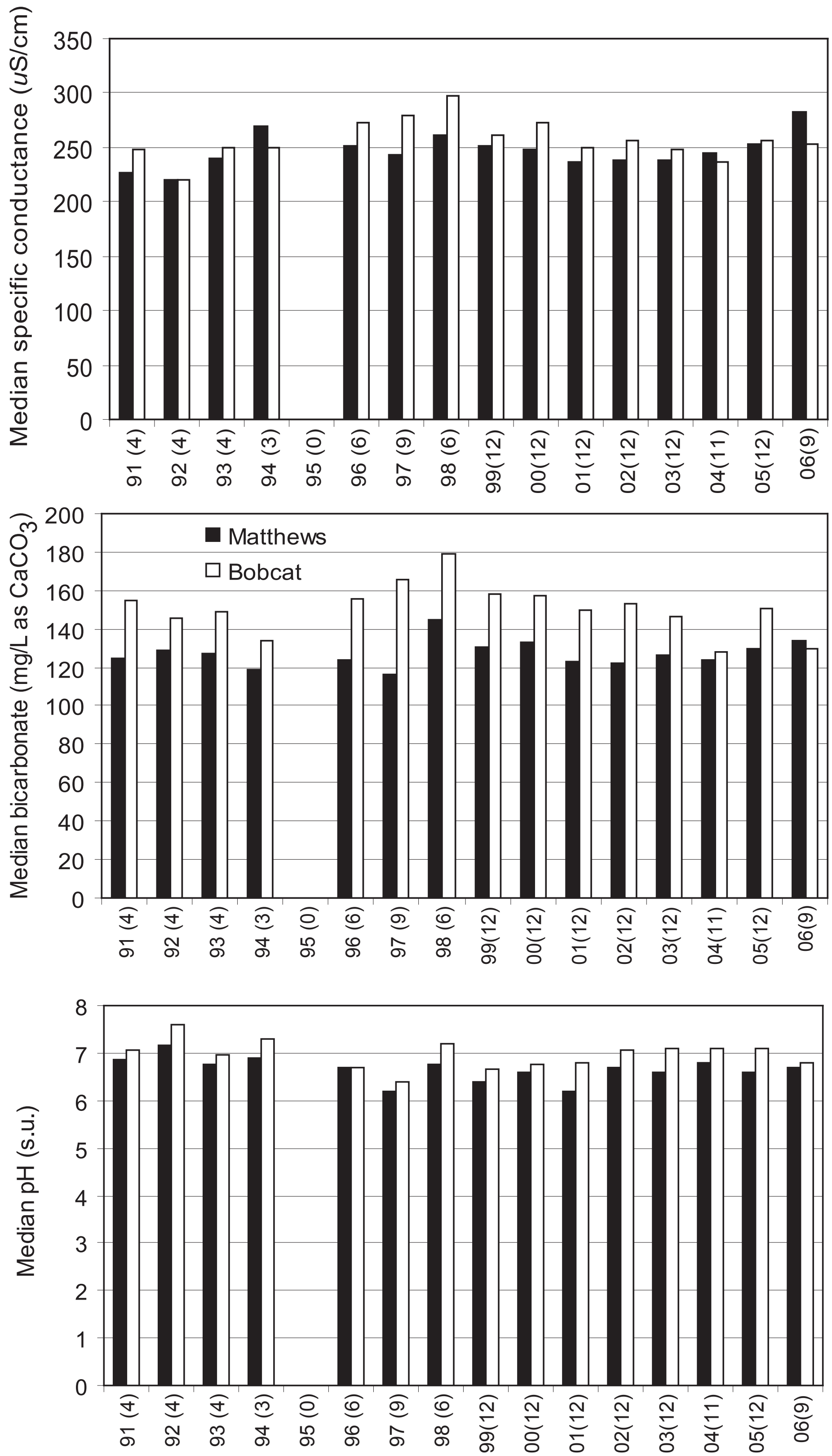

Figure 1. Plots of yearly median specific conductance, bicarbonate, and pH in Bobcat and Matthews Caves, 1991-2006 (number in parentheses is sample size for the year).

Table 1. Summary water-quality data for Bobat and Matthews Caves, October 2005 through September 2006.

Parameter	Units	Lower limit of detection	Bobcat			Matthews		
			min	max	median	min	max	median
Temperature	°C	--	14	19	16.5	15	21	18
Dissolved oxygen	mg/L	--	5.8	11.0	8.4	6.9	13.2	8.4
Total residual chlorine	mg/L	0.02	0	0.18	0.04	0	0.60	0.08
pH	s.u.	--	6.2	7.5	6.8	5.8	7.6	6.7
Alkalinity as $CaCO_3$	mg/L	3	91	147	111	91	136	111
Specific conductance	µS/cm	1	221	322	254	235	425	275
Total dissolved solids	mg/L	1	144	209	165	153	276	179
Sulfate	mg/L	0.08	0.72	3.30	2.25	2.03	5.60	3.09
Chloride	mg/L	0.03	1.83	3.25	2.30	4.00	6.83	4.78
Bromide	mg/l	0.05	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	0.02	<.02	<.02	<.02	<.02	<.02	<.02
Bicarbonate	mg/L	3	111	179	135	111	166	135
Carbonate	mg/L	1	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.02	<.02	0.09	<.02	<.02	0.05	0.02
Nitrite as N	mg/L	0.006	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	0.006	0.356	1.18	0.778	2.08	2.72	2.43
Total NOx as N	mg/L	0.006	0.356	1.18	0.778	2.08	2.72	2.43
Total phosphorus	mg/L	0.01	0.01	0.07	0.03	0.02	0.05	0.03
Orthophosphate as P	mg/L	0.05	<.05	<.05	<.05	<.05	<.05	<.05
Cadmium	µg/L	0.09	<.09	0.32	0.12	<.09	0.44	<.09
Chromium	µg/L	0.8	<.8	3.4	1.1	<.8	0.9	<.8
Lead	µg/L	0.9	<.9	10.6	<.9	<.9	10.2	<.9
Mercury	µg/L	0.08	<.08	<.08	<.08	<.08	<.08	<.08
Total Organic Carbon	mg/L	0.4	<.4	1.86	<.4	<.4	1.12	<.4

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 1.83 to 3.25 mg/L (median, 2.30 mg/L) in Bobcat Cave and from 4.00 to 6.83 mg/L (median, 4.78 mg/L) in Matthews Cave (table 1) in 2005-06. 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 2006 (fig. 2), indicating that water in Matthews Cave likely has a greater connectivity to polluted surface runoff and ground water. 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 0.72 to 3.30 mg/L (median, 2.25 mg/L) in Bobcat and from 2.03 to 5.60 mg/L (median, 3.09 mg/L) in Matthews (table 1) in 2005-06. Over the period 1991 through 2005, median sulfate concentrations in Bobcat were greater than median sulfate in Matthews Cave (fig. 2), except 1998 when median sulfate was slightly greater in Matthews Cave and in 2006 when median sulfate was substantially greater in Matthews. Like chloride, the long-term trend for median sulfate is increasing in Matthews Cave.

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 0.36 to 1.18 mg/L (median, 0.78 mg/L) in Bobcat

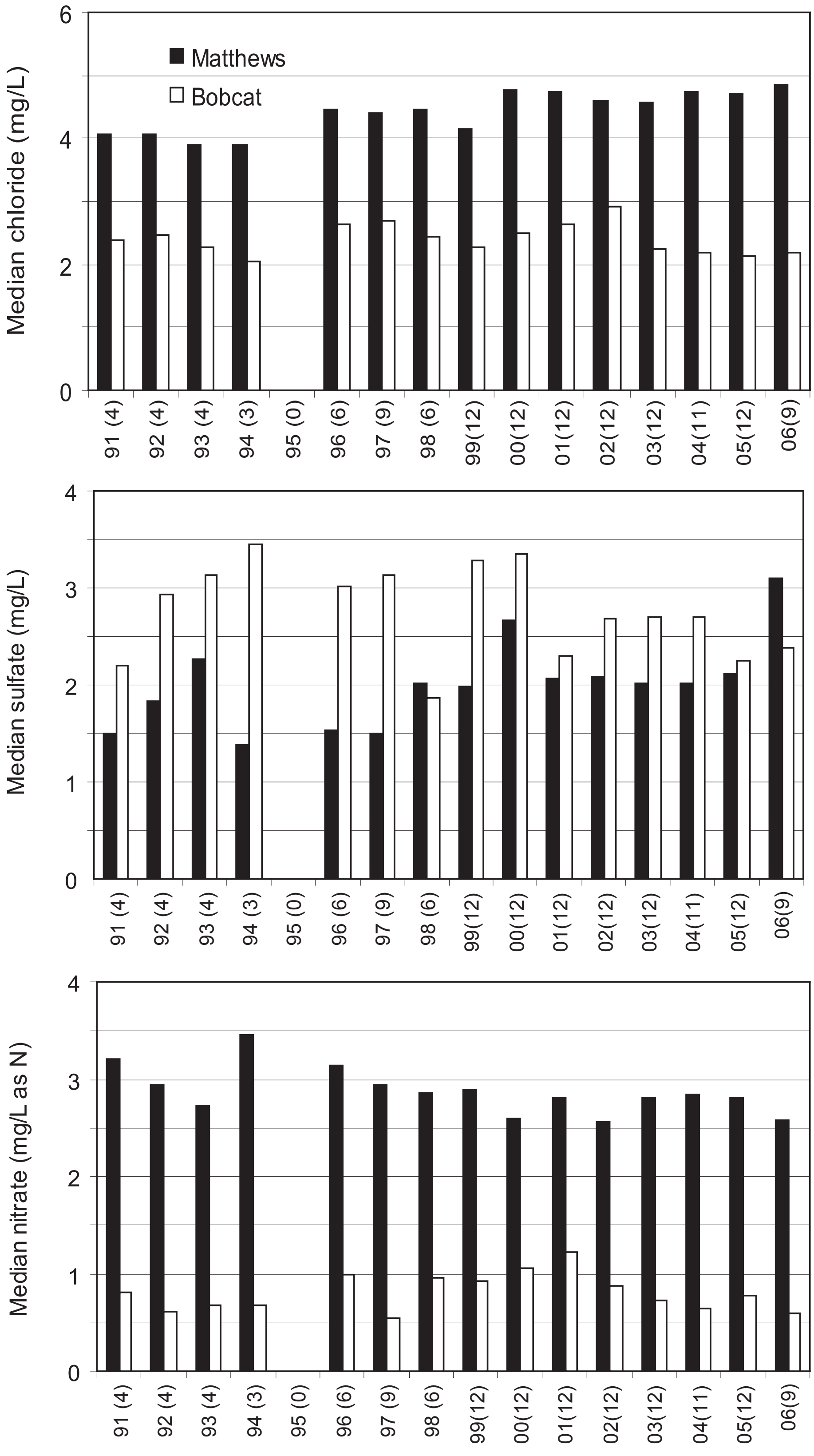

Figure 2. Plots of yearly median chloride, sulfate, and nitrate
in Bobcat and Matthews Caves, 1991-2006
(number in parentheses is sample size for the year).

and from 2.08 to 2.72 mg/L (median, 2.43 mg/L) in Matthews from 2005-06 (table 1). From 1991-2006, the median nitrate concentrations in Bobcat Cave have averaged from about 0.5 to just over 1.0 mg/L, whereas the median concentrations in Matthews Cave have averaged to just less than 3.0 mg/L (fig. 2). Ammonia was detected in four samples from Bobcat Cave in 2005-06 compared to six samples in 2004-05, while ammonia was detected in seven samples from Matthews Cave in 2005-06 (appendix)– the same as in 2003-04 and 2004-05. Phosphorus concentrations during 2005-06 were low in each cave with total dissolved phosphorus ranging from 0.01 to 0.07 mg/L in Bobcat Cave and from 0.02 to 0.05 mg/L in Matthews Cave. Median total phosphorus was 0.03 mg/L in both Bobcat and Matthews Caves (table 1).

Most of the time in natural waters unaffected by pollution, trace metals occur in low concentrations, generally <1.0 µg/L or undetectable. Elevated trace metal concentrations may indicate the presence of a pollution source or a nearby ore deposit. Cadmium was detected in 7 of 12 samples taken from Bobcat Cave and in 4 of 12 samples taken from Matthews Cave during 2005-06 (appendix). Cadmium concentrations in samples from Bobcat ranged from <0.09 to 0.32 µg/L with a median of 0.12 µg/L, while samples from Matthews Cave ranged from <0.09 to 0.44 µg/L with a median of <0.09 µg/L (table 1) in 2005-06. 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 1996-2006 indicate the continued presence of cadmium in both Bobcat and Matthews Caves (fig. 3) with cadmium detections averaging 69.4 percent for Bobcat Cave and 67.4 percent for Matthews Cave over this period (table 2). All samples from Matthews in the period 1991-1994 were near or below detection limits, while a few detections were made in Bobcat Cave in 1992 and 1994 (fig. 3).

Chromium was detected in 7 of 12 samples from Bobcat Cave in 2005-06 (appendix) and ranged from <0.8 to 3.4 µg/L with a median of <1.1 µg/L (table 1). Chromium was detected in 1 of 12 samples from Matthews Cave. The drinking water MCL for chromium (III) is 100 µg/L, the landfill leachate MCL is 50 µg/L, while the

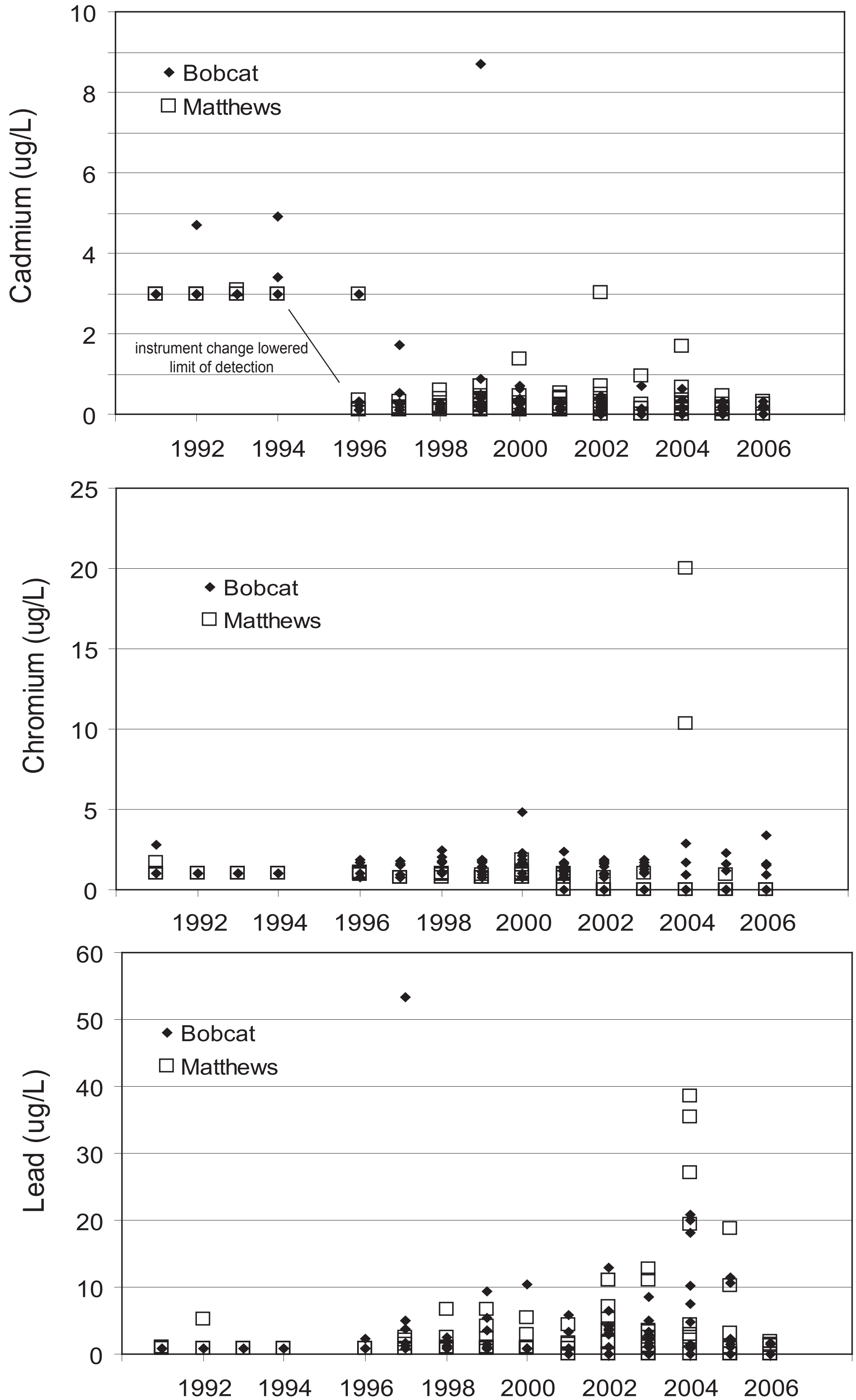

Figure 3. Selected trace metal concentrations of water in Bobcat and Matthews Caves, 1991-2005.

Table 2. Yearly detection rate (percent of samples collected) of selected trace metals in water collected from Bobcat and Matthews Caves, 1996-2006

Year	Sample size	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	9	44	33	44	0	22	33
Average		69.4	67.4	60.3	23.7	51.8	46.4

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 increased sharply this past year to 44 percent (table 2). 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 0 percent in 2006. Chromium detections averaged 60.3 percent for Bobcat Cave and 23.7 percent for Matthews Cave during the period 1996-2006 (table 2).

Lead was detected in 4 of 12 samples from Bobcat Cave in 2005-06, ranging from <0.9 to 10.6 µg/L with a median of <0.9 µg/L. Lead was detected in 5 of 12 samples from Matthews Cave, ranging from <0.9 to 10.2 µg/L with a median of <0.9 µg/L (table 1). 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 (table 2). Lead detections have since declined progressively in each succeeding year to 73 percent in 2004, 58 percent in 2005, and 22 percent for the nine samples in 2006. The maximum lead values for the last eight 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, and 10.6 µg/L through September in 2006. Similarly, the maximum lead values for Matthews Cave the past eight 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, and 10.2 µg/L through September in 2006. Lead detections since 1996 have averaged about 50 percent of all samples collected in each cave (table 2). Maximum lead concentrations have declined steadily since the peak observed in 2004 (fig. 3).

The expanded list of parameters was continued this year to better characterize water-quality conditions and begin building a comprehensive water database for future reference (table 1). Median levels of several other toxic trace metals measured this year were less than detection limits in both caves and included arsenic, beryllium, copper, mercury, nickel, silver, and zinc. Median manganese was less than detection limit in Bobcat and 0.55 µg/L in Matthews Cave. Median chemical oxygen demand (COD) was similar between caves at 72.5 mg/L in Matthews compared to 80.5 mg/L in Bobcat Cave. Median total phenolics and median total organic carbon were both less than detection limits (<3 mg/L and <0.4 mg/L, respectively) 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 2006. 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 4, along with daily rainfall records provided by RSA. The rainfall station is located about five 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. 4). 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. 4). Water exits through fissures and cracks generally to the east of Bobcat Cave at 585 to 586 feet. Monthly variation of water level is greater from November through April, when Bobcat receives

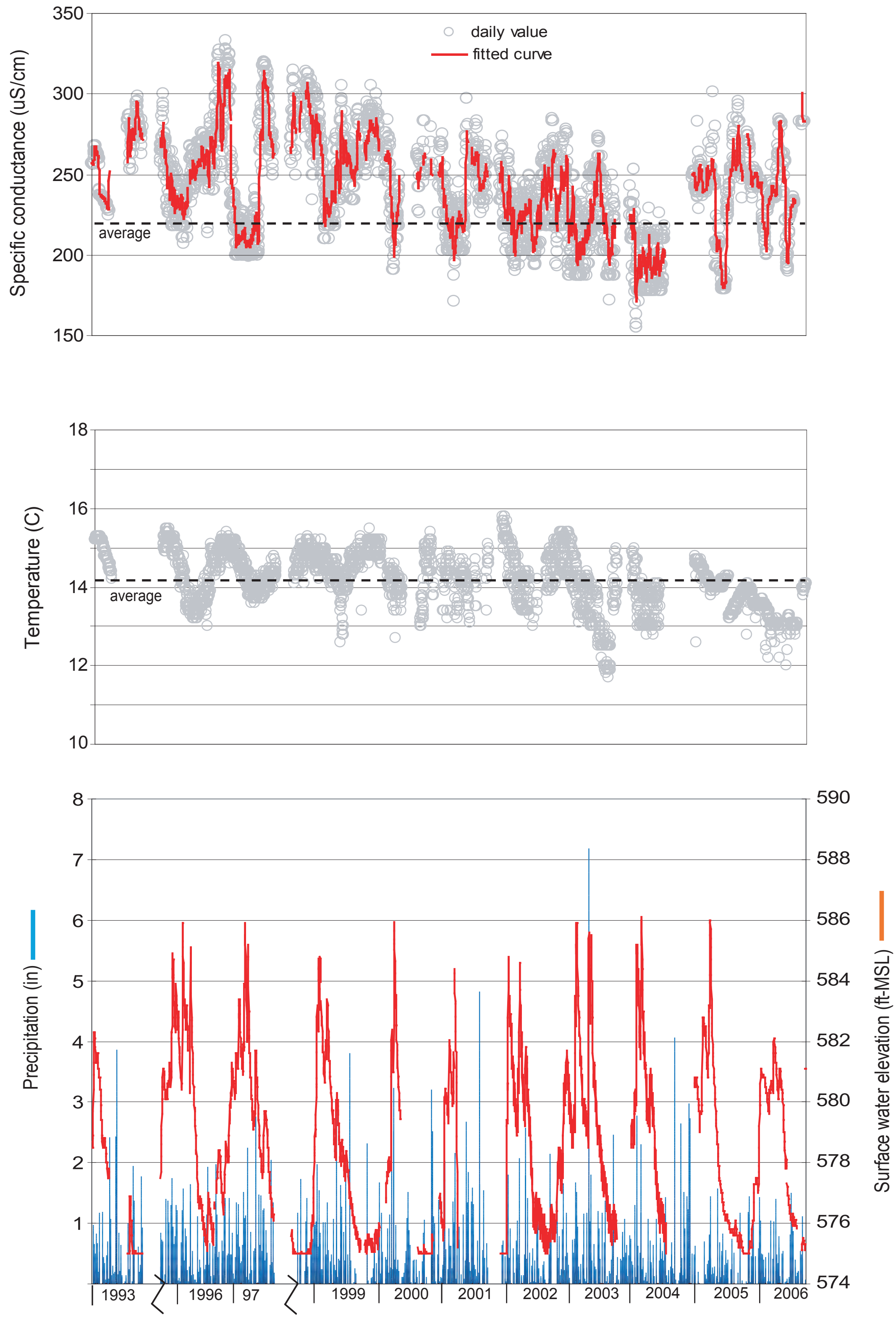

Figure 4. Daily water-quality monitoring data for Bobcat Cave, 1993-2006.

greater quantities of surface runoff. Water is present only in isolated pools and windows at 575 feet. Water level in Bobcat Cave averaged 579.2 ft-msl over the period 1993 through 2006.

Bobcat Cave has a very stable water temperature regime throughout the year, averaging 14.1°C from 1993-2006. Temperature generally varies 2°C throughout the year, ranging from around 13°C to around 15°C (fig. 4). 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 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 2006 was 246 µS/cm, ranging from 211 to 590 µS/cm (fig. 4). 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 on 12 occasions during this study from October 2005 to September 2006. Cave shrimp were observed during six visits. Eight of 50 shrimp observed had oocytes or attached ova (table 3). The highest number of shrimp observed during this period of study was 22 on July 18 (table 3, fig. 5). August generally produces the most sightings of cave shrimp in Bobcat Cave, but this year only five (1

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, November 1990-September 2006.

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

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2006--Continued.

Date	Number observed	Notes[1]
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
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	

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2006--Continued.

Date	Number observed	Notes[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	
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

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2006--Continued.

Date	Number observed	Notes[1]
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.
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

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2006--Continued.

Date	Number observed	Notes[1]
June 11, 2001	0	No counts made (PEO) 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
June 14, 2002	6	Observed from foot of entrance slope to opening to shrimp room; water 2 m in depth, and too deep to enter 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

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2006--Continued.

Date	Number observed	Notes[1]
April 24, 2003	0	Cave sumped
May 28, 2003	0	Cave sumped
June 24, 2003	0	Cave sumped
July 24, 2003	0	Water level 2 feet from ceiling of cave where you enter 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
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

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2006--Continued.

Date	Number observed	Notes[1]
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

[1]- measurements=total length including rostrum

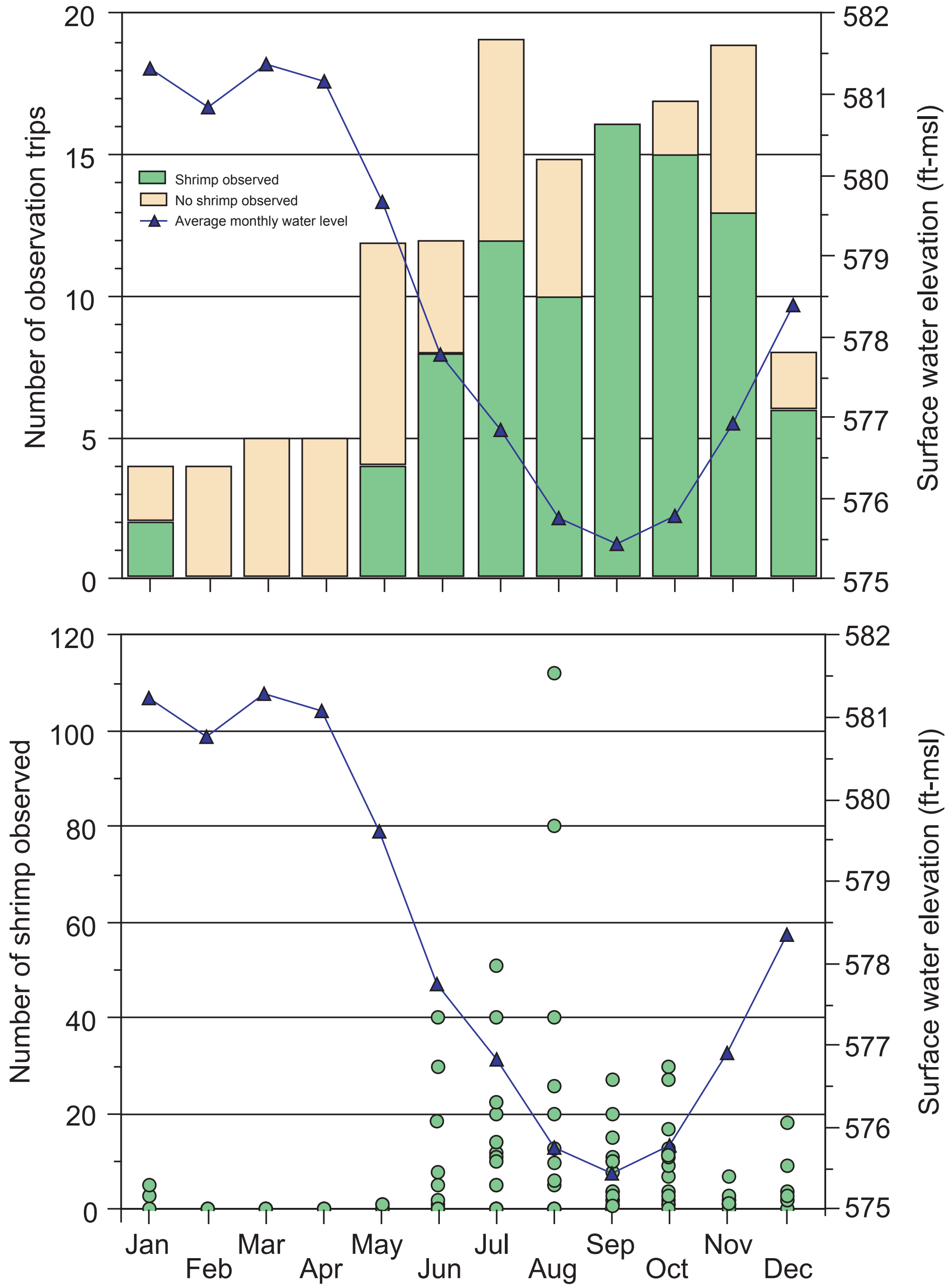

Figure 5. Shrimp observations and counts in Bobcat Cave, 1990-2006.

with oocytes or attached ova) were observed, likely due to extremely low water levels because of a severe drought.

Information concerning long-term trends in the shrimp population in Bobcat Cave can be found in figure 5. June, July, and August are usually the months when shrimp observations are most prevalent, each month having yielded 40 or more shrimp in one or more visits. The upper graph provides a comparison of visits when shrimp were observed on a monthly basis to 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 likely related to low water levels 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 shrimp movement to deeper ground water with receding water level, possibly evolved to prevent individuals from being stranded in isolated pools. Counts are usually high from June through August as accessibility improves and shrimp are present in large numbers. By September, when observation conditions are optimal, shrimp have likely completed or nearly completed their migration to a lower water level. As shown in the upper graph of figure 5, 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. Only three of 10 observation trips in May have yielded shrimp, probably because, while the shrimp are present in high numbers before migration begins, conditions for observation are hampered by high water. 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 counted.

CONCLUSIONS AND RECOMMENDATIONS

Results of ongoing studies related to the biological, physical, and chemical components of the Bobcat Cave and Matthews Cave environments have provided an expanding information base and improved our understanding of the complex interrelationships between these components. Of particular note for this year’s water sampling was the continued decline of maximum concentrations of cadmium, chromium, and lead in both cave systems. In past years a trend of increasing concentrations of these trace metals was observed but results of this year’s sampling confirmed a steady declining trend of these metals. Also, the rate of trace metal detections was lower this year compared to previous years. Our previous concerns of possible low-level contamination of Bobcat Cave by water from deeper aquifers have been reduced somewhat by this year’s data. Deeper aquifer water may still be the source of trace metal spikes because (1) the immediate surface drainage into Bobcat Cave has recently been protected by removing cattle and other agricultural uses and returned to an unmanaged state--effectively removing surface runoff of pollutants into the cave as a source, and (2) high lead measurements were generally in samples taken during low water levels when deep ground water dominated cave hydrology. Both cadmium and lead continue to be detected in concentrations sufficient to be of concern with regard to calculated criteria for protection of aquatic life. The yearly flux of trace metal concentrations over ten years of investigation appear to minimally affect cave shrimp based on their continued presence and persistence in Bobcat Cave.

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 ground water, which may have consequences for Bobcat Cave and the Alabama cave shrimp. The quality of surface runoff into Bobcat Cave from the local watershed should be better documented.

- Improvements have been made in the methodology for fingerprinting ground water, aiding in determining sources of recharge. This methodology should be used to determine the origin of deep ground water in the Bobcat Cave aquifer. As evidence is now beginning to suggest, contaminants may be transported to Bobcat Cave via deeper ground-water aquifers. The information determined through this study would provide enhanced understanding of cave hydrology and improve protection from encroaching urbanization and its effects on ground water.

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APPENDIX

Water-quality sampling data
2005-2006

Site Date	Units	Bobcat 12-Oct-05	Bobcat 16-Nov-05	Bobcat 15-Dec-05	Bobcat 18-Jan-06	Bobcat 16-Feb-06	Bobcat 15-Mar-06
Time	24-hr	10:45	11:45	11:20	13:15	9:40	10:45
Temperature	°C	18	14	14	14	15	16
Dissolved oxygen	mg/L	9.6	nd	5.8	10.3	11	nd
Total residual chlorine	mg/L	0.02	0.04	<.02	0.04	<.02	0.12
pH	s.u.	6.4	7.5	6.7	7.3	7.4	7.4
Alkalinity as $CaCO_3$	mg/L	144	142	112	102	109	107
Specific conductance	μS/cm	254	316	250	225	247	242
Total dissolved solids	mg/L	165	205	163	146	161	157
Sulfate	mg/L	1.23	1.24	3.00	2.12	2.88	2.38
Chloride	mg/L	2.63	2.39	2.02	1.83	1.92	2.18
Bromide	mg/l	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Bicarbonate	mg/L	176	173	136	124	133	130
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	<.02	0.03	<.02	<.02	<.02	0.04
Nitirite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	0.823	0.902	1.18	0.558	0.487	0.756
Total Nox as N	mg/L	0.823	0.902	1.18	0.558	0.487	0.756
Total phosphorus	mg/L	0.02	0.01	0.03	0.04	0.03	0.05
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Cadmium	μg/L	0.17	0.11	0.32	<.09	0.31	0.2
Chromium	μg/L	2.3	1.6	1.2	0.9	<.8	<.8
Lead	μg/L	0.97	<.9	10.6	<.9	<.9	<.9
Mercury	μg/L	<.08	<.08	<.08	<.08	<.08	<.08
Total Organic Carbon	mg/L	<.4	<.4	<.4	<.4	<.4	<.4

Site Date	Units	Bobcat 19-Apr-06	Bobcat 11-May-06	Bobcat 27-Jun-06	Bobcat 11-Jul-06	Bobcat 23-Aug-06	Bobcat 20-Sep-06
Time	24-hr	11:45	10:30	11:00	11:55	10:25	14:35
Temperature	°C	18	16	17	19	19	17
Dissolved oxygen	mg/L	6.1	nd	8.4	9.5	7.2	6.3
Total residual chlorine	mg/L	0.04	0.04	0.04	0.1	0.18	0.04
pH	s.u.	6.8	7.5	6.2	6.2	6.2	6.8
Alkalinity as $CaCO_3$	mg/L	113	106	94	91	129	147
Specific conductance	μS/cm	266	266	253	221	293	322
Total dissolved solids	mg/L	173	173	164	144	190	209
Sulfate	mg/L	3.30	2.76	2.42	0.72	1.08	0.74
Chloride	mg/L	1.92	2.2	2.48	3.08	3.25	2.91
Bromide	mg/l	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Bicarbonate	mg/L	138	129	115	111	157	179
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	<.02	<.02	0.03	<.02	0.09	<.02
Nitirite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	0.356	0.389	0.588	1.10	0.799	0.841
Total Nox as N	mg/L	0.356	0.506	0.588	1.10	0.799	0.841
Total phosphorus	mg/L	0.03	0.07	0.04	0.03	0.04	0.02
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Cadmium	μg/L	0.16	<.09	<.09	<.09	<.09	0.13
Chromium	μg/L	<.8	<.8	<.8	1.5	1.6	3.4
Lead	μg/L	<.9	<.9	<.9	<.9	1.6	1.4
Mercury	μg/L	<.08	<.08	<.08	<.08	<.08	<.08
Total Organic Carbon	mg/L	<.4	1.49	1.86	<.4	0.8	<.4

Site		Matthews	Matthews	Matthews	Matthews	Matthews	Matthews
Date	Units	12-Oct-05	16-Nov-05	15-Dec-05	18-Jan-06	16-Feb-06	15-Mar-06
Time	24-hr	11:45	10:30	10:20	12:40	9:00	10:05
Temperature	°C	18	16	15	15	16	16
Dissolved oxygen	mg/L	9.3	13.2	7	9.1	9.9	nd
Total residual chlorine	mg/L	0.6	0.06	<.02	0.02	<.02	0.1
pH	s.u.	6.6	7.5	6.1	6.7	6.9	6.9
Alkalinity as $CaCO_3$	mg/L	125	121	104	101	112	102
Specific conductance	μS/cm	264	425	245	235	283	247
Total dissolved solids	mg/L	172	276	159	153	184	161
Sulfate	mg/L	2.42	3.02	4.04	3.07	2.26	2.03
Chloride	mg/L	5.01	4.59	4.00	4.44	4.62	4.28
Bromide	mg/l	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Bicarbonate	mg/L	152	147	127	123	136	124
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.02	0.03	<.02	0.03	<.02	<.02
Nitirite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	2.32	2.32	2.08	2.58	2.72	2.49
Total Nox as N	mg/L	2.32	2.32	2.08	2.58	2.72	2.49
Total phosphorus	mg/L	0.03	0.02	0.05	0.03	0.03	0.05
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Cadmium	μg/L	<.09	<.09	0.44	<.09	0.31	0.26
Chromium	μg/L	<.8	0.9	<.8	<.8	<.8	<.8
Lead	μg/L	<.9	0.98	10.2	<.9	1.4	1.3
Mercury	μg/L	<.08	<.08	<.08	<.08	<.08	<.08
Total Organic Carbon	mg/L	0.56	<.4	<.4	<.4	<.4	0.43

Site		Matthews	Matthews	Matthews	Matthews	Matthews	Matthews
Date	Units	19-Apr-06	11-May-06	27-Jun-06	11-Jul-06	23-Aug-06	20-Sep-06
Time	24-hr	10:45	9:45	10:15	10:50	12:00	13:15
Temperature	°C	18	18	18	21	21	18
Dissolved oxygen	mg/L	6.9	nd	7.7	9	7.8	7.6
Total residual chlorine	mg/L	0.04	0.05	0.1	0.14	0.3	0.14
pH	s.u.	7.2	7.6	5.8	5.8	6.1	6.6
Alkalinity as $CaCO_3$	mg/L	102	91	110	111	121	136
Specific conductance	μS/cm	261	267	282	287	330	363
Total dissolved solids	mg/L	170	174	183	187	215	236
Sulfate	mg/L	5.60	2.92	3.10	3.18	3.86	4.34
Chloride	mg/L	4.85	4.7	5.82	6.83	6.42	6.41
Bromide	mg/l	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Bicarbonate	mg/L	124	111	134	135	148	166
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	<.02	0.02	0.02	0.04	0.05	<.02
Nitirite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	2.61	2.24	2.67	2.67	2.37	2.25
Total Nox as N	mg/L	2.61	2.24	2.67	2.67	2.37	2.25
Total phosphorus	mg/L	0.05	0.05	0.04	0.03	0.02	0.03
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Cadmium	μg/L	0.26	<.09	<.09	<.09	<.09	<.09
Chromium	μg/L	<.8	<.8	<.8	<.8	<.8	<.8
Lead	μg/L	<.9	<.9	<.9	<.9	1.8	<.9
Mercury	μg/L	<.08	<.08	<.08	<.08	<.08	<.08
Total Organic Carbon	mg/L	<.4	1.12	<.4	<.4	<.4	<.4