

GEOLOGICAL SURVEY OF ALABAMA

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WATER QUALITY AND BIOLOGICAL MONITORING IN BOBCAT AND MATTHEWS CAVES, REDSTONE ARSENAL, ALABAMA, 1990-2005

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INTRODUCTION

The Alabama cave shrimp, *Palaemonias alabamiae* 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 performed 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). 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 2004, 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.

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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 last two 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

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). 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).

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 57 dissolved-oxygen meter. Hydrogen-ion concentration (pH) was measured with a Corning Model M-105 pH meter with associated specific-ion electrode. Specific conductance was measured in micro Siemens per centimeter ($\mu\text{S}/\text{cm}$) with a YSI Model 34 Conductance-Resistance meter and attached 0.1K conductance bridge. 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.

A depth-integrated grab sample of water was collected monthly at each station from which the following raw and filtered ($0.45\mu\text{m}$) 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 ($\text{pH} < 2.0$ with sulfuric acid) bag, one filtered-acidified ($\text{pH} < 2.0$ with nitric acid) sample in a white polyethylene bottle, and one filtered-acidified ($\text{pH} < 2.0$ 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. 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 one 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 been made with varying degrees of effort and frequency since November 1990. The current 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 2004 through September 2005 (appendix). Water in Bobcat Cave generally has a slightly higher specific conductance, and hence higher dissolved solids content, 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 2004-05 ranged from 126 to 158 mg/L with a median of 149 mg/L, which was higher than the preceding year in Bobcat Cave, while the median bicarbonate in Matthews at 127 mg/L, and ranging from 108 to 135 mg/L, was similar to the preceding year (table 1; fig. 1). Yearly median bicarbonate in Bobcat ranged from a low of 128 mg/L in 2004 to a high of 179

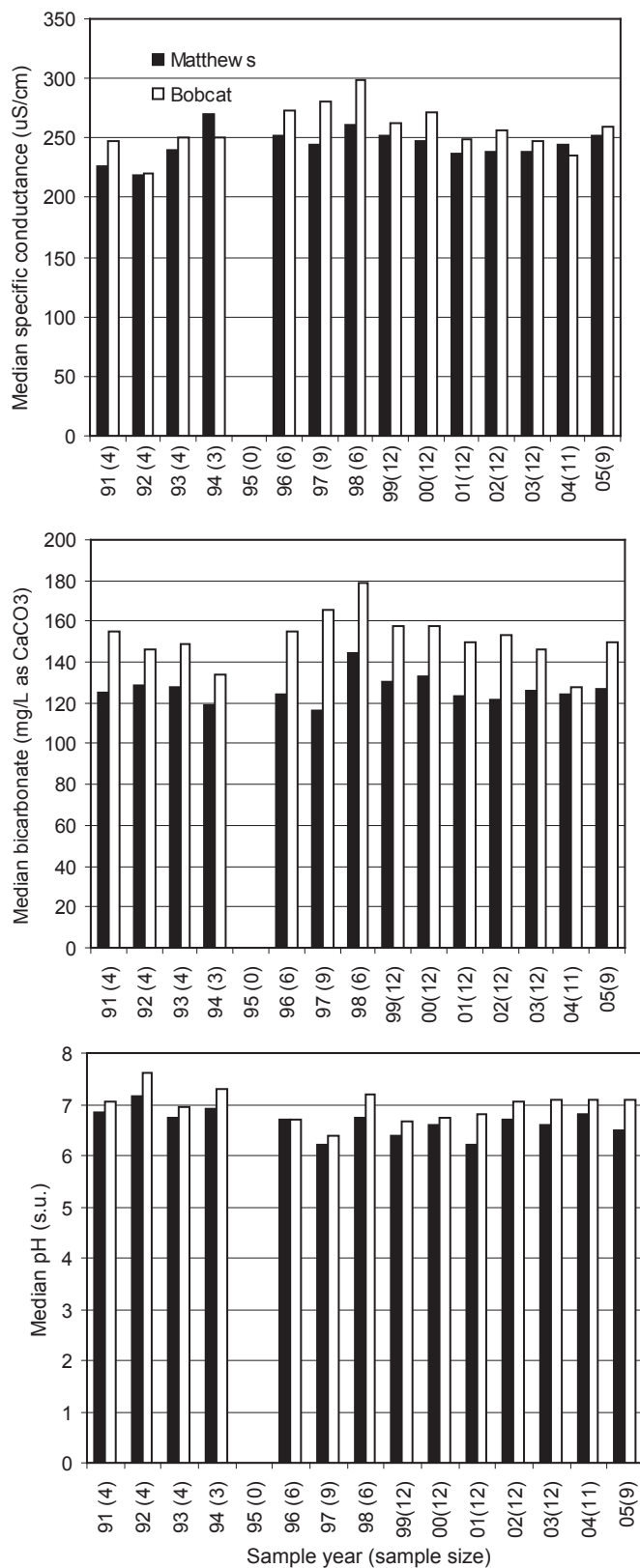


Figure 1. Plots of yearly median specific conductance, bicarbonate, and pH in Bobcat and Matthews Caves, 1991-2005.

Table 1. Summary water-quality data for Bobcat and Matthews Caves,
October 2004 through September 2005.

Parameter	Units	LLD	Bobcat			Matthews		
			min	max	median	min	max	median
Temperature	°C	--	15	20	17	14	21	18
Dissolved oxygen	mg/L	--	5.0	12.0	6.4	1.0	11.2	6.4
Total residual chlorine	mg/L	0.02	<.02	0.90	0.02	0.00	0.35	0.02
pH	s.u.	--	6.0	7.4	6.8	5.6	6.9	6.3
Alkalinity as CaCO ₃	mg/L	3	103	130	122	89	111	104
Specific conductance	μ S/cm	1	219	295	247	236	296	251
Total dissolved solids	mg/L	1	123	155	138	115	150	140
Sulfate	mg/L	0.001	0.73	3.35	2.80	1.42	3.68	1.93
Chloride	mg/L	0.03	1.67	2.89	2.14	3.64	5.04	4.70
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	1	126	158	149	108	135	127
Carbonate	mg/L	1	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.02	<.02	0.047	0.010	<.02	0.08	0.03
Nitrite as N	mg/L	0.006	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	0.006	0.323	0.983	0.647	1.840	3.400	2.955
Total Nox as N	mg/L	0.006	0.323	9.830	0.647	1.840	3.400	2.955
Total phosphorus	mg/L	0.01	<.01	0.03	0.02	<.01	0.04	0.03
Orthophosphate as P	mg/L	0.05	<.05	<.05	<.05	<.05	<.05	<.05
Cadmium	μ g/L	0.09	<.09	0.62	0.13	<.09	0.36	0.16
Chromium	μ g/L	0.8	<.8	0.9	<.8	<.8	<.8	<.8
Lead	μ g/L	0.9	<.9	20.9	1.7	<.9	27.0	0.5
Mercury	μ g/L	0.08	<.08	<.08	<.08	<.08	<.08	<.08
Total Organic Carbon	mg/L	0.4	<.4	1.35	<.4	<.4	0.64	<.4

mg/L in 1998, while this parameter in Matthews Cave 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 2004-05 ranged from 4.2 to 7.4 (median, 6.8), while pH of Matthews Cave ranged from 4.6 to 6.9 (median, 6.3) 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 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 1.67 to 2.89 mg/L (median, 2.14 mg/L) in Bobcat Cave and from 3.64 to 5.04 mg/L (median, 4.70 mg/L) in Matthews Cave (table 1). The median concentrations of chloride in Matthews Cave have consistently varied in the range of about 1.5 to 2.0 times the median chloride concentrations in Bobcat Cave over the period 1991 through 2005 (fig. 2), indicating that water in Matthews Cave likely has a greater connectivity to polluted surface runoff and ground water.

Sulfate concentrations were similar between caves in 2004-05 ranging from 0.73 to 3.35 mg/L (median, 2.80 mg/L) in Bobcat and from 1.42 to 3.68 mg/L (median, 1.93 mg/L) in Matthews (table 1). 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.

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

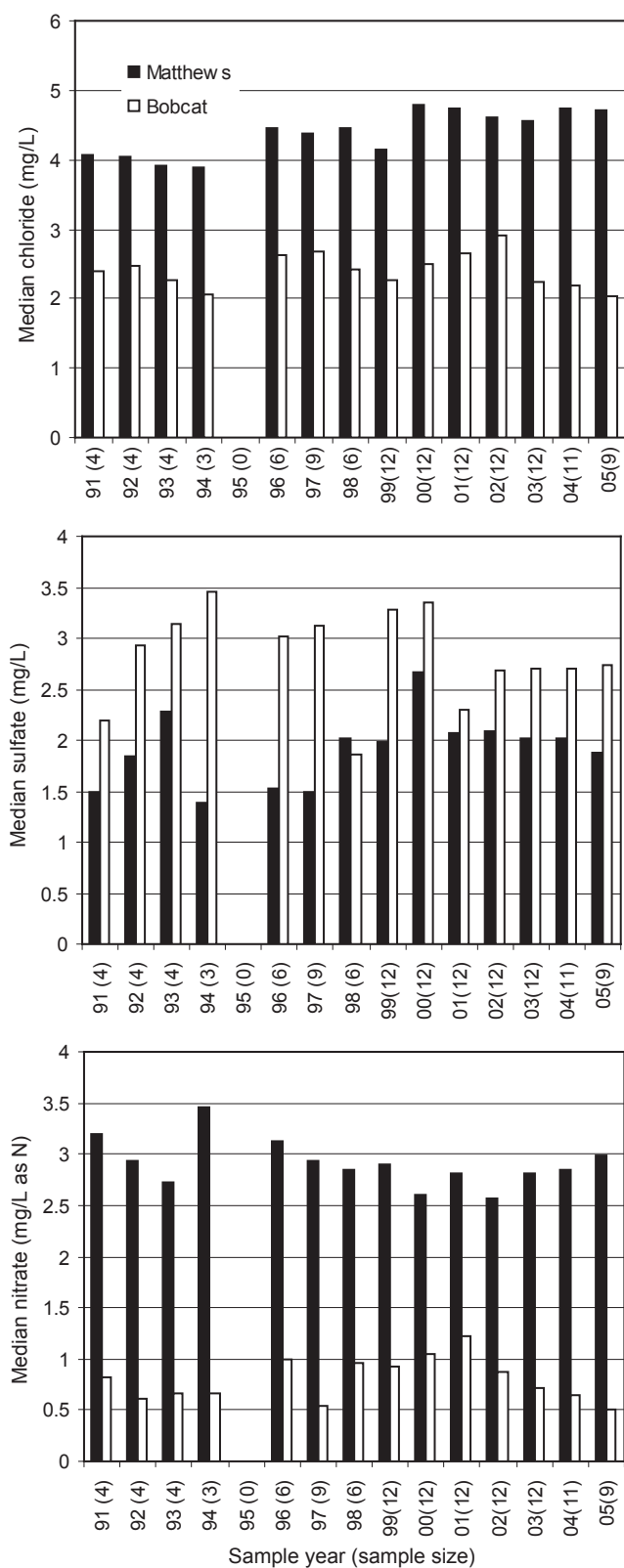


Figure 2. Plots of yearly median chloride, sulfate, and nitrate in Bobcat and Matthews Caves, 1991-2005.

distances. Excessive nitrate concentrations (>10 mg/L NO_3 as N) in the blood may cause a condition known as methemoglobinemia “blue baby syndrome” in small children because the blood lacks sufficient ability to deliver oxygen to cells. Upon contact with sunlight, excess nitrate can contribute to nuisance algal blooms in surface waters. Nitrate ranged from 0.32 to 0.98 mg/L (median, 0.65 mg/L) in Bobcat and from 1.84 to 3.40 mg/L (median, 2.95 mg/L) in Matthews from 2004-05 (table 1). From 1991-2005, the median nitrate concentrations in Bobcat Cave varied from about 0.5 to just over 1.0 mg/L, whereas the median concentrations in Matthews Cave varied around 3.0 mg/L (fig. 2). Ammonia was detected in six samples from Bobcat Cave in 2004-05 compared to two samples in 2003-04, while ammonia was detected in seven samples from Matthews Cave in 2004-05 (appendix)- the same as in 2003-04. Phosphorus concentrations during 2004-05 were low in each cave with total dissolved phosphorus ranging from <0.01 to 0.03 mg/L in Bobcat Cave and from <0.01 to 0.04 mg/L in Matthews Cave. Median total phosphorous was 0.02 mg/L in Bobcat and 0.03 in Matthews (table 1).

Trace metals occur in low concentrations, generally <1.0 $\mu\text{g/L}$ or undetectable, much of the time in natural waters unaffected by pollution. 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 9 of 12 samples taken from Matthews Cave during 2004-05 (appendix). Samples from Bobcat ranged from <0.09 to 0.62 $\mu\text{g/L}$ with a median of 0.13 $\mu\text{g/L}$, while samples from Matthews Cave ranged from <0.09 to 0.36 $\mu\text{g/L}$ with a median of 0.16 $\mu\text{g/L}$ (table 1). The drinking water maximum contaminant level (MCL) for cadmium is 5.0 $\mu\text{g/L}$, the MCL for leachate from sanitary landfills is 10 $\mu\text{g/L}$, whereas the chronic and acute criteria for protection of aquatic life are 1.13 $\mu\text{g/L}$ and 3.92 $\mu\text{g/L}$, respectively, calculated using a hardness of 100 mg/L. Data from 1996-2005 indicate the continued presence of cadmium in both Bobcat and Matthews Caves (fig. 3) with cadmium detections averaging 70.5 percent for Bobcat Cave and 71.7 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 2 of 12 samples from Bobcat Cave in 2004-05 (appendix) and ranged from <0.8 to 0.9 $\mu\text{g/L}$ with a median of <0.8 $\mu\text{g/L}$ (table 1). Chromium was not detected

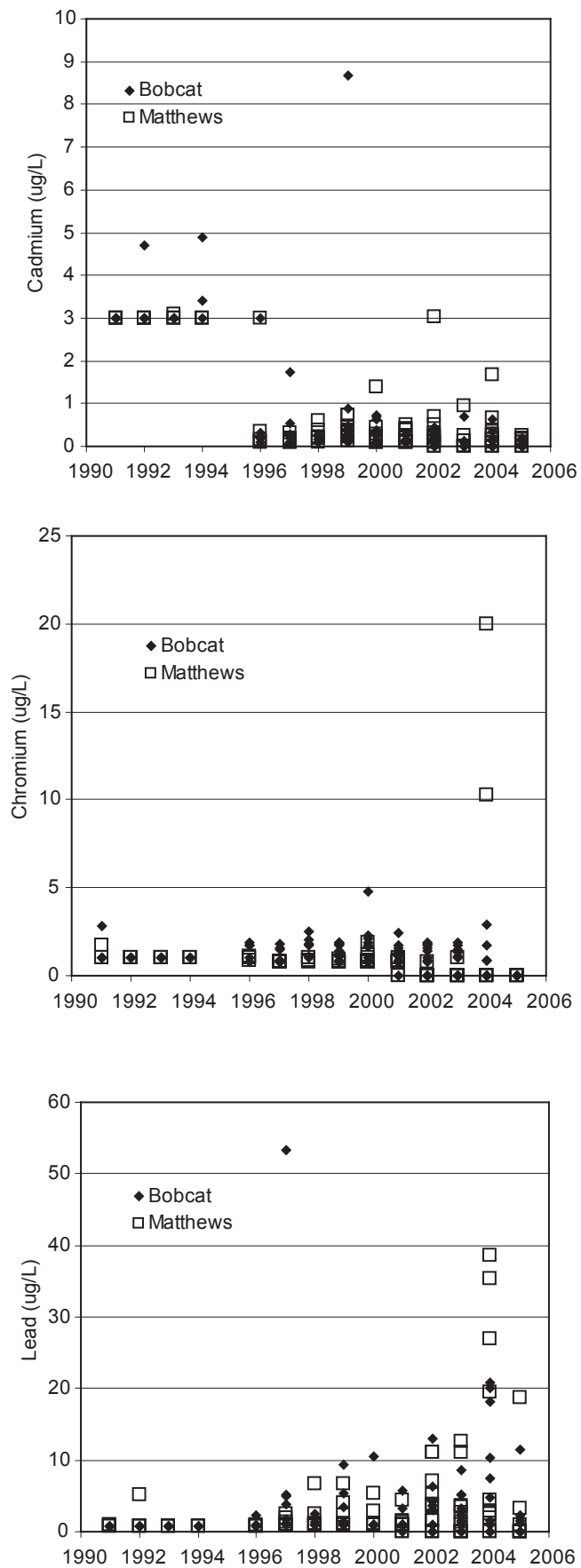


Figure 3. Selected trace metal concentrations of water in Bobcat and Matthews Caves, 1991-2005.

Table 2. Yearly detection rate (percent of samples collected) of selected trace metals in water collected from Bobcat and Matthews Caves, 1996-2004

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	9	44	67	0	0	56	33
Average		70.5	71.7	59.4	25.3	54.6	46.8

in any of the 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 chronic and acute aquatic-life criteria are 207 µg/L and 1,736 µg/L, respectively, for a hardness of 100 mg/L. The chromium detection rate decreased in Bobcat Cave from 1998-2000, rose to 75 percent in 2001, and has declined steadily to 36 percent in 2004 (table 2). Chromium detection rate in Matthews Cave declined from a high of 67 percent in 1998 to a low of 8 percent in 2002 and 2003. Chromium detections in Matthews Cave increased in 2004 to 18 percent with two measurements (10.3 µg/L and 20 µg/L) exceeding levels of all previous samples analyzed since 1991. Chromium detections averaged 59.4 percent for Bobcat Cave and 25.3 percent for Matthews Cave during the period 1996-2005 (table 2). Chromium has not been detected in any of the nine samples analyzed for 2005, and the overall detection rate of chromium has declined steadily the last several years in Bobcat Cave. Chromium was not detected in either cave from 1992 to 1994, while one detection in each cave was made in 1991 (fig. 3).

Lead was detected in 8 of 12 samples from Bobcat Cave in 2004-05, ranging from <0.9 to 20.9 µg/L with a median of 1.7 µg/L. Lead was detected in 6 of 12 samples from Matthews Cave, ranging from <0.9 to 27.0 µg/L with a median of 0.5 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 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), and declining to 73 percent in 2004. Detections have declined in the nine samples made in 2005 to 56 percent. 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, and 11.4 µg/L through September in 2005. Similarly, the maximum lead values for Matthews Cave the last 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, and 18.7 µg/L through September, 2005. Lead detections since 1996 have averaged about 50 percent

of all samples collected in each cave (table 2). Maximum lead concentrations declined substantially in 2005 compared to 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, manganese, nickel, and silver. Median zinc levels were less than detection limit ($<4 \mu\text{g/L}$) in Bobcat Cave and near detection limit ($8.4 \mu\text{g/L}$) in Matthews Cave. Median chemical oxygen demand (COD) was similar between caves at 89.5 mg/L in Matthews compared to 81.5 mg/L in Bobcat Cave. Median total phenolics and median total organic carbon were both less than detection limits ($<3 \text{ mg/L}$ and $<0.4 \text{ mg/L}$, 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 2005. 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

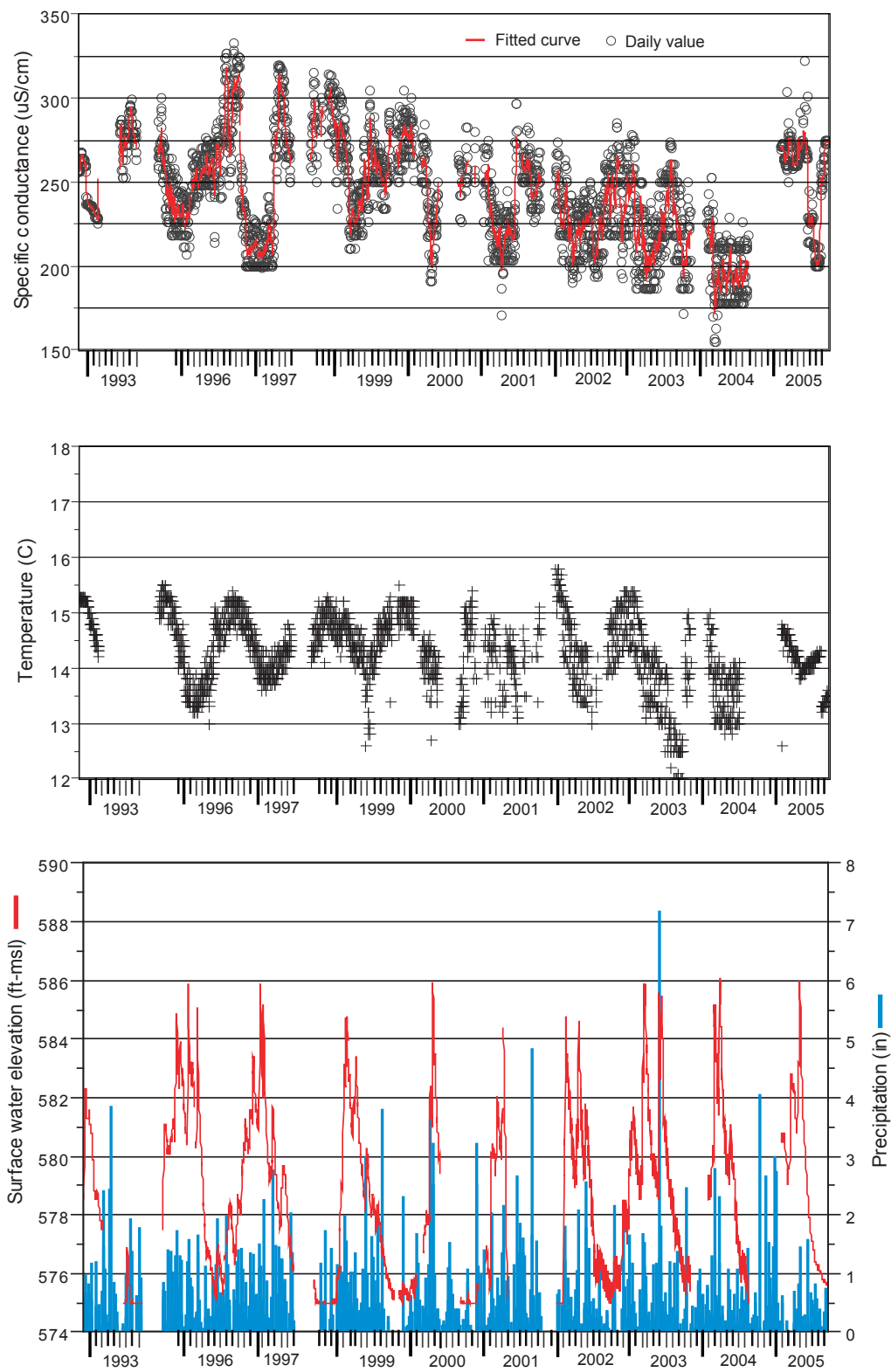


Figure 4. Daily water-quality monitoring data for Bobcat Cave, 1993-2005.

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 greater quantities of surface runoff. Water is present only in isolated pools and windows at 575 feet. Water level in Bobcat Cave averaged 578 ft-msl over the period 1993 through 2004.

Bobcat Cave has a very stable water temperature regime throughout the year, averaging 14.3°C from 1993-2005. 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. Extremes during the period of October 2004 through August 2005 were 14.8°C measured in January and 13.2°C measured in July. 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. A rapid recovery to normal water temperature usually followed the spike.

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 interact with the cave. Average specific conductance from 1993 through 2005 was 243 $\mu\text{S}/\text{cm}$, ranging from 171 to 333 $\mu\text{S}/\text{cm}$ (fig. 4). The lowest average monthly specific conductance occurs in April when water levels are high, whereas the highest monthly average specific conductance occurs in October and November when water levels are low (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 infiltrate Bobcat Cave.

BIOLOGICAL MONITORING

Bobcat Cave was visited on 12 occasions from October 2004 to September 2005. Cave shrimp were observed during three visits. Twelve of 55 shrimp observed had oocytes or attached ova (table 3). The highest number of shrimp observed in 2005 was 30 on June 21 (table 3, fig. 5).

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, November 1990-September 2005

Date	Number specimens 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 1.75 inches long with "black spot" on back
May 25, 1992	1	Female with large oocytes or attached ova, 1.75-2 inches 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

Table 3.-- Chronological list of Alabama cave shrimp observations in
Bobcat Cave, December, 1990-September, 2005--Continued.

Date	Number specimens observed	Notes ¹
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 22-27.2mm
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 range 12.7 mm, two measured range 25 mm
September 3, 1993	8	
September 12, 1993	10	Eight measured range <12.7 mm; two measured range 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 length ranges <12.7 mm
October 22, 1993	1	
October 28, 1993	3	One measured 22 mm

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2005--Continued.

Date	Number specimens observed	Notes ¹
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	
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

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2005--Continued.

Date	Number specimens observed	Notes ¹
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.
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 (<i>Procyon lotor</i>).
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.

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2005--Continued.

Date	Number specimens observed	Notes ¹
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 (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

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2005--Continued.

Date	Number specimens observed	Notes ¹
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 two 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-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

Table 3.-- Chronological list of Alabama cave shrimp observations in Bobcat Cave, December, 1990-September, 2005--Continued.

Date	Number specimens observed	Notes ¹
December 21, 2004	0	No shrimp observed; cave passage sumped
January 21, 2005	0	No shrimp observed; cave passage sumped
February 24, 2005	0	No shrimp observed; cave passage sumped
March 24, 2005	0	No shrimp observed; cave passage sumped
April 26, 2005	0	No shrimp observed; cave passage sumped
May 2005	0	Water level much lower, but no shrimp observed
June 21, 2005	30	Six with oocytes or attached ova
July 21, 2005	0	Water low; crayfish observed
August 17, 2005	10	One with oocytes or attached ova; water reduced to isolated pools
September 20, 2005	15	Five with oocytes or attached ova; water reduced to isolated pools; with Bryan Phillips of RSA

¹- measurements=total length including rostrum

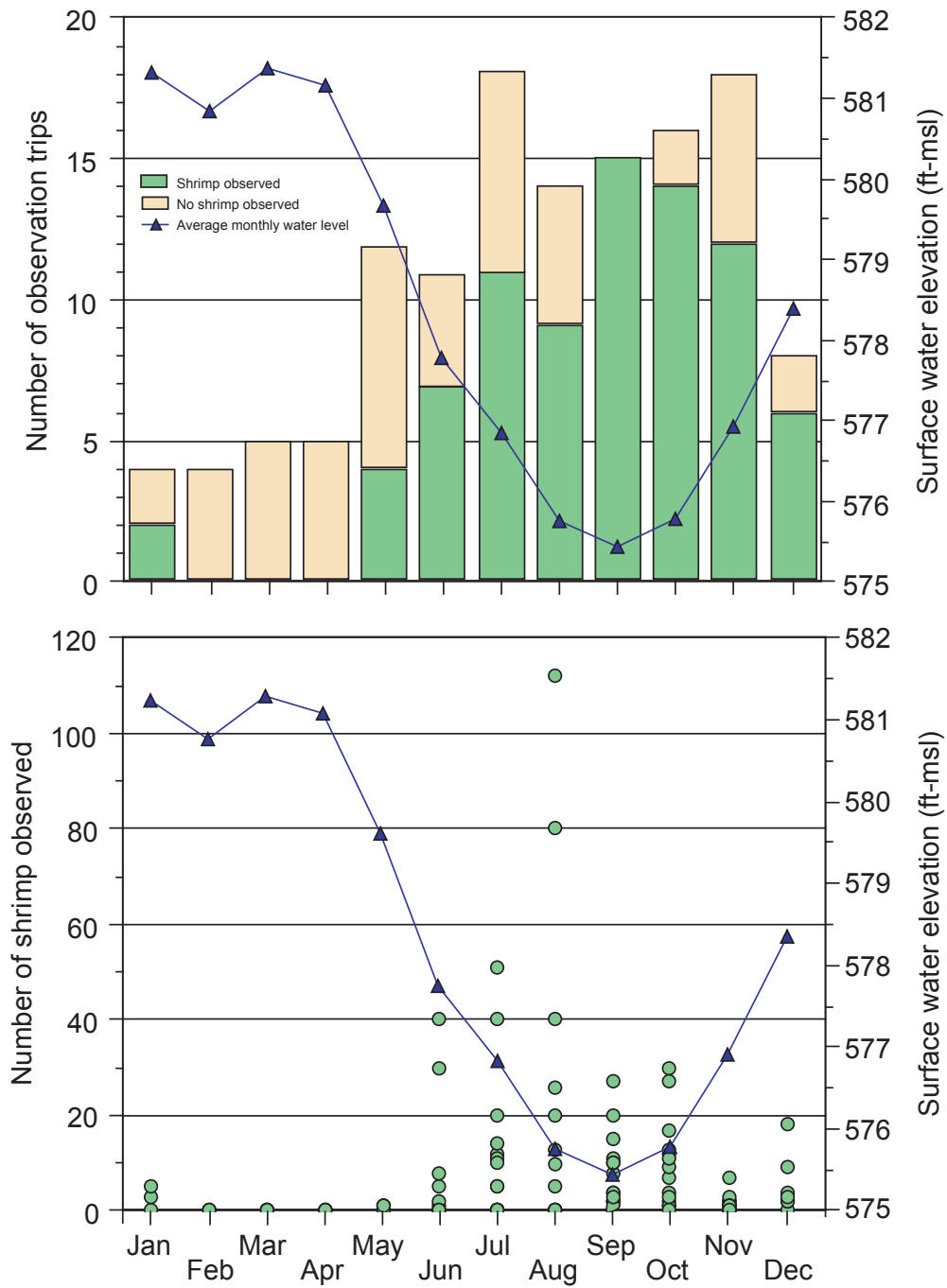


Figure 5. Shrimp observations and counts in Bobcat Cave, 1990-2005.

August generally produces the most sightings of cave shrimp in Bobcat Cave, and 10 were observed during that month, 1 with oocytes or attached ova. During average water years, the cave is accessible past the foot of the entrance slope from June through November. During this sample year, unusually high rainfall totals prevented access from September through April, thus limiting shrimp observations. Also, observations were frequently made by personnel inexperienced in working with cave shrimp, and sampling efficiency may have been lower than normal.

Bobcat Cave has been visited 158 times since November 1990 (table 3). Alabama cave shrimp were observed during 80 of those trips. A total of 946 sightings includes about 109 individuals (11.5%) with oocytes or attached ova (table 3). These data are based on efforts expended under widely varying conditions, frequency, levels of effort, and with the possibility of repeat sightings during one visit and subsequent visits. No shrimp have ever been observed in February, March, or April, because seasonal high water levels consistently limit observations to the pool at the foot of the entrance slope. Unusually low precipitation in January 2001 contributed to the only sighting of cave shrimp during that month. Shrimp have been observed in all other months, from a minimum of 3 (1 gravid female, 33.3%) total for the cumulative months of May, to a high of 327 (56 gravid females, 18.7%) accumulated for the month of August. June has yielded 86 total (12 gravid females, 14.0%), July, 185 (at least 9 gravid females, 4.9%), September, 118 (11 gravid females, 9.3%), October, 138 (21 gravid females, 15.2%), November, 30 (1 gravid female, 3.3%), December, 38 (1 gravid females, 2.6%), and January, 8 (0 gravid females) (table 3). The observation of six shrimp with oocytes or attached ova among 30 individuals observed in June 2005 is only the second observation of shrimp with oocytes or attached ova observed for that month during 15 years of observation. The reason for this disparity is unknown.

Information concerning long-term trends in the shrimp population in Bobcat Cave can be found in figure 5. June, July, and August are 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 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 declining 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 showed a 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. This is certainly not conclusive but may be a workable theory explaining spikes of trace metal contamination during past years. 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 be having minimal effect on 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 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 will 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 show, 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
2004-2005

Site Date	Units	Bobcat 27-Oct-04	Bobcat 23-Nov-04	Bobcat 21-Dec-04	Bobcat 21-Jan-05	Bobcat 24-Feb-05	Bobcat 24-Mar-05
Time	24-hr	13:10	11:35	10:35	10:35	10:30	10:35
Temperature	°C	19	16	15	16	17	15
Dissolved oxygen	mg/L	8.3	5.7	6.4	5	5.4	7.1
Total residual chlorine	mg/L	0.9	<.02	<.02	0.2	<.02	<.02
pH	s.u.	6.0	6.5	6.3	7	7.4	7.3
Alkalinity as CaCO ₃	mg/L	114	105	103	118	123	124
Specific conductance	μ S/cm	243	219	219	227	259	261
Total dissolved solids	mg/L	158	142	142	148	168	170
Sulfate	mg/L	2.95	1.15	3.11	2.74	3.34	3.29
Chloride	mg/L	2.79	2.64	1.67	2.04	1.92	1.88
Bromide	mg/l	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Bicarbonate	mg/L	139	128	126	144	150	151
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.023	0.02	<.02	0.03	0.031	0.047
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	0.741	0.891	0.556	0.365	0.501	0.406
Total Nox as N	mg/L	0.741	0.891	0.556	0.365	0.501	0.406
Total phosphorus	mg/L	0.021	0.013	0.03	0.032	0.027	<.01
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Cadmium	μ g/L	0.62	0.14	0.15	<.09	<.09	0.2
Chromium	μ g/L	0.9	0.9	<.8	<.8	<.8	<.8
Lead	μ g/L	20.9	7.5	4.87	1.9	1.2	<.9
Mercury	μ g/L	<.08	<.08	<.08	<.08	<.08	<.08
Total Organic Carbon	mg/L	<.4	<.4	0.45	<.4	<.4	<.4

Site Date	Units	Bobcat 27-Apr-05	Bobcat 19-May-05	Bobcat 21-Jun-05	Bobcat 21-Jul-05	Bobcat 17-Aug-05	Bobcat 15-Sep-05
Time	24-hr	10:35	10:55	13:05	11:05	12:00	10:50
Temperature	°C	17	17	20	18	20	19
Dissolved oxygen	mg/L	7.5	5.9	6.4	5.4	8.2	12
Total residual chlorine	mg/L	<.02	0.2	0.04	<.02	0.04	0.16
pH	s.u.	6.1	6.4	7.4	6.1	7.1	7.4
Alkalinity as CaCO ₃	mg/L	125	122	118	0	126	130
Specific conductance	μ S/cm	263	236	241	250	264	295
Total dissolved solids	mg/L	171	153	157	163	172	192
Sulfate	mg/L	3.35	2.86	1.76	1.66	0.73	0.96
Chloride	mg/L	1.81	1.95	2.23	2.43	2.89	2.59
Bromide	mg/l	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Bicarbonate	mg/L	152	149	144	0	153	158
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	<.02	<.02	0.022	<.02	<.02	<.02
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	0.323	0.418	0.738	0.983	0.962	0.975
Total Nox as N	mg/L	0.323	0.418	0.738	9.83	0.962	0.975
Total phosphorus	mg/L	<.01	0.014	0.026	0.019	0.025	0.016
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Cadmium	μ g/L	<.09	0.15	<.09	<.09	0.12	0.13
Chromium	μ g/L	<.8	<.8	<.8	<.8	<.8	<.8
Lead	μ g/L	2.2	1.45	<.9	11.4	<.9	<.9
Mercury	μ g/L	<.08	<.08	<.08	<.08	<.08	<.08
Total Organic Carbon	mg/L	<.4	<.4	<.4	<.4	<.4	1.35

Site Date	Units	Matthews 27-Oct-04	Matthews 23-Nov-04	Matthews 21-Dec-04	Matthews 21-Jan-05	Matthews 24-Feb-05	Matthews 24-Mar-05
Time	24-hr	12:00	10:45	9:50	9:45	9:45	9:35
Temperature	°C	20	18	14	17	15	16
Dissolved oxygen	mg/L	9.2	6	6.5	7.3	5.9	7.9
Total residual chlorine	mg/L	<.02	<.02	<.02	0.3	<.02	<.02
pH	s.u.	5.7	6.3	6.1	6.2	6.6	6.9
Alkalinity as CaCO ₃	mg/L	107	102	102	104	104	110
Specific conductance	μ S/cm	243	284	245	256	250	254
Total dissolved solids	mg/L	158	185	159	166	163	165
Sulfate	mg/L	3.68	3.49	1.62	1.65	1.98	2.5
Chloride	mg/L	4.18	4.41	4.86	4.97	4.61	4.64
Bromide	mg/l	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Bicarbonate	mg/L	130	124	124	127	127	134
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	0.037	0.031	0.03	<.02	0.025	0.032
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	1.94	2.5	3.25	3.33	2.98	2.98
Total Nox as N	mg/L	1.94	2.5	3.25	3.33	2.98	2.98
Total phosphorus	mg/L	0.035	0.022	0.039	0.033	0.029	0.024
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Cadmium	μ g/L	0.26	0.36	0.16	0.15	0.11	<.09
Chromium	μ g/L	<.8	<.8	<.8	<.8	<.8	<.8
Lead	μ g/L	27	4.47	2.9	3.2	0.9	<.9
Mercury	μ g/L	<.08	<.08	<.08	<.08	<.08	<.08
Total Organic Carbon	mg/L	<.4	<.4	<.4	<.4	<.4	<.4

Site Date	Units	Matthews 27-Apr-05	Matthews 19-May-05	Matthews 21-Jun-05	Matthews 21-Jul-05	Matthews 17-Aug-05	Matthews 15-Sep-05
Time	24-hr	9:40	10:05	11:40	10:05	11:20	9:50
Temperature	°C	17	19	21	18	21	21
Dissolved oxygen	mg/L	1	6.2	6	4.6	8.4	11.2
Total residual chlorine	mg/L	0.35	0.3	0.04	<.02	0.04	0.1
pH	s.u.	5.6	5.8	6.7	6.2	6.5	6.8
Alkalinity as CaCO ₃	mg/L	100	109	109	0	89	111
Specific conductance	μ S/cm	242	252	236	240	262	296
Total dissolved solids	mg/L	157	164	153	156	170	192
Sulfate	mg/L	1.87	1.64	1.88	2.27	1.42	2.33
Chloride	mg/L	4.7	5.04	4.7	4.71	3.64	4.87
Bromide	mg/l	<.05	<.05	<.05	<.05	<.05	<.05
Fluoride	mg/L	<.02	<.02	<.02	<.02	<.02	<.02
Bicarbonate	mg/L	122	133	133	0	108	135
Carbonate	mg/L	<1	<1	<1	<1	<1	<1
Ammonia as N	mg/L	<.02	<.02	<.02	0.077	0.027	<.02
Nitrite as N	mg/L	<.006	<.006	<.006	<.006	<.006	<.006
Nitrate as N	mg/L	3.28	3.4	2.93	2.69	1.84	2.49
Total Nox as N	mg/L	3.28	3.4	2.93	2.69	1.84	2.49
Total phosphorus	mg/L	<.01	0.038	0.031	0.028	0.033	0.031
Orthophosphate as P	mg/L	<.05	<.05	<.05	<.05	<.05	<.05
Cadmium	μ g/L	<.09	0.24	<.09	0.18	0.19	0.1
Chromium	μ g/L	<.8	<.8	<.8	<.8	<.8	<.8
Lead	μ g/L	<.9	<.9	<.9	18.7	<.9	<.9
Mercury	μ g/L	<.08	<.08	<.08	<.08	<.08	<.08
Total Organic Carbon	mg/L	<.4	<.4	<.4	<.4	<.4	0.64

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