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AN EVALUATION OF THE MUSSEL FAUNA IN THE NORTH RIVER SYSTEM, 2008

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By
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In cooperation with the Alabama Department of Conservation and Natural Resources
Division of Wildlife and Freshwater Fisheries

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CONTENTS

FIGURES

TABLES

AN EVALUATION OF THE MUSSEL FAUNA IN THE NORTH RIVER SYSTEM, 2008

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ABSTRACT

During the spring and summer of 2008, mussel sampling in the North River system yielded 15 species, with 13 represented by live animals or fresh dead shells and two represented by weathered dead shells only. Two mussel collections made in the system during an unrelated study in April 2005 were also included. Approximately 62 person-hours of time were expended sampling, with 34 hours at 14 main channel stations and 28 hours at 15 tributary stations. A cumulative total of 155 mussels either live, fresh dead, weathered dead, or relic were collected, including 139 (90%) represented by either live animals or fresh dead shells. A catch per unit effort (CPUE) of 2.2 mussels per hour was determined for species collected either live or fresh dead. One live and one fresh dead specimen of the federally listed dark pigtoe, *Pleurobema furvum*, were collected at one tributary station, and one live or fresh dead specimen of the federally listed orange-nacre mucket, *Hamiota perovalis,* was collected at each of three stations, two in a tributary and one in the main channel. Shallow bed sediment quality was also determined from one-time composite grab samples from four stations. Low concentrations of constituents potentially toxic to freshwater mussels suggest no immediate concern to the health of the mussel population.

INTRODUCTION

The mussel and fish faunas of the Mobile River Basin are noteworthy for their high degrees of endemism and diversity. Those phenomena can be attributed to the large size of the basin, numerous habitat types available due to the variety of physiographic types found in the basin, geographic barriers such as the Fall Line, and the proximity of the basin to adjacent drainages with diverse faunas (Williams, 1982). Hinkley (1906) reported 40 mussel species from the Tombigbee River system alone, while Williams and others (1992) reported that 50 species were known to have occurred in the upper Tombigbee (upstream of the confluence of the Tombigbee and Black Warrior Rivers) and 48 in the Black Warrior system, based on taxonomic revisions in recent decades. Williams and others (2008), in a comprehensive review of the mussels of Alabama, tallied 51 species known from the Black Warrior drainage. Direct effects of anthropogenic factors such as impoundment, eutrophication, sedimentation, pollution, and channel modifications and the resultant fragmenting of populations, however, have caused a decline in the mussel fauna (Hartfield, 1994; Mott and Hartfield, 1994).

Currently, 17 species of mussels in the Mobile River Basin are recognized as endangered or threatened by the U.S. Fish and Wildlife Service (USFWS) and 14 species in the genus *Pleurobema* endemic to the basin are considered extinct by the USFWS (Hartfield, 1994). The type locality for one of these extinct species, *Pleurobema hagleri*, is reported to be the North River and was reported to exist prior to 1920 (van der Schalie, 1981). Williams and others (2008) revised the nomenclature of numerous species and recognize *P. rubellum* as the senior synonym and consider *P. furvum* and *P. hagleri* to be junior synonyms of *P. rubellum*, but concede that subsequent genetic analysis may further revise the group. However, since *P. furvum* is still recognized by USFWS as a listed species in the North River, that name will be used herein to prevent confusion.

Collections at numerous stations in the upper North River system (upstream of Lake Tuscaloosa) from 1991 to 1993 and in 1996 documented 14 species (McGregor and Pierson, 1999). That total included eight species collected live, five species represented by fresh dead material, and one species by a weathered dead shell only. Two species subsequently afforded federal protection, the dark pigtoe, *Pleurobema furvum*, and the orange-nacre mucket, *Hamiota perovalis*, were collected live. Another protected species previously reported from the North River, the triangular kidneyshell, *Ptychobranchus greenii*, was not collected, nor was *Pleurobema hagleri*, a species known from the drainage but considered extinct by the USFWS.

Freshwater mussels are benthic filter-feeding organisms and as such are exposed to metals and other pollutants that are dissolved in water, associated with suspended sediments, or deposited in bottom sediments (Naimo, 1995). Because mussels are relatively long-lived, generally sedentary in nature, easily collected, large enough to provide sufficient tissue mass for analysis, tolerant of a wide assortment of pollutants, and known to bioconcentrate or bioaccumulate contaminants, their collective value as indicator organisms for evaluation of long-term ecosystem function and health is well known.

While relatively little information is available on the lethal limits of various pollutants to freshwater mussels, ongoing research documents tolerances of various species and life history stages of mussels (Newton and Bartsch, 2007; Newton and Cope, 2007; Cope and others, 2008).

The toxic effects of pollutants on mussels have been examined in some acute toxicity tests, but the sublethal effects of long-term exposure to low environmental concentrations are poorly understood (see Naimo, 1995, for review of effects of heavy metals). Also, it is widely understood that, despite improvements in modern effluent treatment facilities, freshwater mollusks continue to be affected by ammonia, chlorine, copper, zinc, elevated temperature, organic waste, suspended solids, and nutrients.

The accumulation of contaminants in mussel tissue depends on the presence of the chemical in a form that is available for uptake by the animal into its tissue (Spacie and Hamelink, 1985). This “bioavailability” is determined by numerous environmental or chemical factors, such as which chemical species is present and in what concentration, solubility of the compound in water compared to its tendency to adsorb onto organic matter, hardness of water, presence of competing compounds, sediment or water pH, level of sediment oxygenation, concentration of organic or inorganic carbon, total suspended solids concentration of the water, and water temperature. Bioavailability is also dependent on biological factors, such as age or body size, gender, reproductive status, and species. Adsorption may occur by direct exposure to the water column and movement across cell membranes (bioconcentration), from particulate matter filtered from the water and digested, or from sediment interstitial water (Elder and Collins, 1991; Spacie and Hamelink, 1985). Various studies have shown that the major route of uptake of organic contaminants for freshwater and marine bivalves is from water, where chemicals desorb off of sediment or suspended particles into the water column or interstitial water and are taken up by mollusks (Boryslawskyj and others, 1987; Kauss and Hamdy, 1985, 1991; Livingstone and Pipe, 1992). Adults, which are predominantly filter feeders that collect plankton and organic particles from the water column, may be more affected by exposure to pollutants in the water column, while juveniles take up contaminants from sediments or sediment interstitial water (Yeager and others, 1994). Highest contaminant levels found in sediments in many temperate lakes and rivers often occur in the top 30 cm (Rada and others, 1989, 1990). Adult freshwater mussels tend to burrow up to 25 cm into the substrate, while juvenile mussels typically burrow less than 8 cm (Pennak, 1978; McMahon, 1991; Neves and Widlak, 1987).

A review of all available literature on this subject is not practical here, but some discussion is warranted. Acute toxicity studies, with death as the endpoint and that usually last from a few days to several weeks, determine concentrations of pollutants that kill 50% of test organisms (LC_{50}). Chronic toxicity tests evaluate sublethal effects of exposure to contaminants for weeks or months and measure such parameters as excretion rate, energy stores, growth, and a variety of other biological characteristics. Tests have been performed on different species at various life history stages and with different rates of exposure (both time and concentration) and different combinations of contaminants and ambient physical and chemical conditions. Generally, the metals most toxic to freshwater mussels include cadmium, chromium, copper, mercury, nickel, and zinc (Keller and Zam, 1991; Naimo, 1995), with mercury, copper, and cadmium the most toxic (Khangarot and Ray, 1987). It should be noted that freshwater mussels become stressed at metal concentrations much lower than those reported in acute toxicity tests, and that most tests are conducted under laboratory conditions and might not reflect conditions in nature (Naimo, 1995). Exposures to metals and other contaminants may not be immediately lethal, but over time may interrupt metabolic activities, enzyme function, respiration, and other important biological activities, leading to death. Organic contents of the sediment and water column are also very important in the ability of mussels to uptake toxins. Graney and others (1984) observed that Asian clams (*Corbicula fluminea*) decreased the uptake of cadmium as the organic content of test substrates increased, and that clams in tanks with no substrate or with sand only had much higher tissue burdens than those in tanks with organic or clay-enriched substrates. They also found that clams accumulated more cadmium at 21°C than at 9°C and at pH 7.8 than at pH 5.0. Jacobson and others (1997) reported that juvenile mussels are at greater risk to contamination than adults due to their shallow residency in benthic sediments, where toxicants such as metals may be sequestered at high levels.

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STUDY AREA

The Mobile River Basin is the largest Gulf of Mexico river basin east of the Mississippi River, draining about 43,683 square miles (mi^2) in Alabama, Mississippi, Georgia, and

Tennessee, including 32,207 mi^2, or 62 percent, of the land area of Alabama (Mettee and others, 1996). The Tombigbee River system is the westernmost tributary of the Mobile Basin and drains an area of 19,984 mi^2 in Alabama and Mississippi, and the Black Warrior River drains 6,228 mi^2 in north central Alabama. The North River is a major tributary of the Black Warrior River, draining an area of 425 mi^2 in Fayette, Tuscaloosa, and Walker Counties (see inset map, fig. 1). The North River joins the Black Warrior River near the Fall Line near Tuscaloosa.

Flow rates in the upper North River are influenced by the relatively poor recharge of the underlying shales and sandstones of the Pottsville Formation, and the river often goes dry or is reduced to isolated pools during dry seasons. At the Fall Line, the substrate changes from sandstone and shale bedrock to the sand, gravel, and clay of the Coker, Gordo, and Eutaw Formations, which are important sources of ground water, resulting in streams that are well-sustained even during dry years (Mettee and others, 1996).

Within the study area North River varied from 60 to 75 feet in width at the lowermost sites to only 15 to 20 feet at the most upstream locations. Stream habitat varied from long pools with slow current to shoal areas with riffles and runs and slow to moderate current. Substrate was highly variable, consisting of bedrock, boulders, angular rubble, cobble, gravel, sand, and silt. Evidence of beaver (*Castor canadensis*) activity was observed at most sites, and in several reaches beaver dams extending across the main channel had altered the riverine habitat. At these sites pool habitat was increased and riffle habitat was often inundated. At most stations the stream banks were stable and vegetated with either upland hardwood or pine-hardwood forest. A few clear-cuts were observed in the watershed and agricultural activities were common. Recent and old surface mining operations were observed.

METHODS

Sampling was confined to the main channel of North River and selected tributaries upstream of Lake Tuscaloosa, a water supply reservoir impounding the lower river since 1969. Collections were made during June, July, and September 2008, with an additional two stations sampled during an unrelated study in April 2005 included. Stations were located with the aid of DeLorme's Atlas and Gazetteer, county highway maps, or U.S. Geological Survey 1:250,000 topographic maps. They were accessed at bridge crossings, foot trails, or via canoe. Mussel collections were made by hand, often with the aid of mask and snorkel. Nomenclature follows Williams and others (2008) except for the recognition of *Pleurobema furvum* over *Pleurobema* *hagleri*. Most live animals were identified and returned to the stream where they were found. A few problematic specimens were retained for verification and possible genetic work and were deposited in the University of Alabama Unionid Collection. Representative specimens of shell material collected were retained and will be deposited in the North Carolina State Museum of Natural Sciences.

Composite bed sediment samples were collected from four stations in the North River system on January 28, 2008, and transported to the laboratory in a chilled cooler. Samples were prepared for chemical analysis according to procedures described in Fishman and Friedman (1989) and U.S. Environmental Protection Agency (USEPA) (1999b) according to the methods for parameters to be determined. Subsequently, chemical analyses of the sediment samples were conducted in accordance with the USEPA (McLean, 1982), Crock and others (1987), USEPA (1983, 1993, 1994, 1999a, 1999b), and Fishman and Friedman (1989). The sediment samples were collected in accordance with the Quality Assurance-Quality Control Plan for The Geological Survey of Alabama (O'Neil and Meintzer, 1995).

RESULTS AND DISCUSSION

MUSSEL SAMPLING

During this project 29 stations were sampled including 14 main channel and 15 tributary stations (table 1, fig. 1). A total of 15 species were collected, with 13 represented by live animals or fresh dead shells and two represented by weathered dead shells only (table 2). Approximately 62 person-hours of time were expended sampling, with 34 hours in main channel North River stations and 28 hours in tributary stations. A cumulative total of 155 mussels either live, fresh dead, weathered dead, or relic were collected, including 139 (90%) either live or represented by fresh dead shells. A CPUE of 2.2 mussels per hour was determined for species collected either live or fresh dead.

During the previous survey of the system (McGregor and Pierson, 1999), 14 species were collected with 13 represented by live animals or fresh dead shells. A cumulative total of 224 mussels were found at 30 stations, with 196 (88%) either live or fresh dead. However, effort was not reported for that study and no meaningful CPUE values for comparison can be calculated. During each study the exotic Asian clam, *Corbicula fluminea*, was commonly encountered at all stations, with the exception of a few headwater and tributary stations, and will not be discussed further.

Table 1-Summary information for stations sampled in the North River system, Alabama, 2005 and 2008.

Station number	Locality[1]	County	Map coordinates
Main Channel North River stations			
NR1	North River at mouth of Cripple Creek	Tuscaloosa	N 33° 27.950' W 87° 34.593'
NR2	North River at County Road 38	Tuscaloosa	N 33° 28.786' W 87° 35.830'
NR3	North River downstream of Wittson Bridge	Tuscaloosa	N 33° 30.359' W 87° 43.877'
NR4	North River at tributary on right bank	Tuscaloosa	N 33° 30.809' W 87° 34.676'
NR5	North River downstream of Wittson Bridge	Tuscaloosa	N 33° 31.488' W 87° 34.606'
NR6	North River downstream of Wittson Bridge	Tuscaloosa	N 33° 32.612' W 87° 35.090'
NR7	North River at Wittson Bridge	Tuscaloosa	N 33° 32.992' W 87° 35.830'
NR8	North River at confluence of Cedar Creek	Tuscaloosa	N 33° 34.753' W 87° 37.383'
NR9	North River at Alabama Highway 18	Fayette	N 33° 37.858' W 87° 39.311'
NR10	North River at mouth of Clear Creek	Fayette	N 33° 39.363' W 87° 38.677'
NR11	North River at County Road 30	Fayette	N 33° 40.847' W 87° 37.914'
NR12	North River at mouth of Lowery Branch	Fayette	N 33° 45.612' W 87° 36.624'
NR13	North River at County Road 63	Fayette	N 33° 46.118' W 87° 36.066'
NR14	North River at Alabama Highway 102	Fayette	N 33° 48.320' W 87° 35.025'
Tributary stations			
BnC1	Boone Creek downstream of Co. Rd. 55	Tuscaloosa	N 33° 32.575' W 87° 36.265'
BnC2	Boone Creek at County Rd. 63/T	Tuscaloosa	N 33° 32.164' W 87° 37.375'
BvC1	Beaver Creek near AL Hwy. 13/F	Fayette	N 33° 45.204' W 87° 37.896'
ClC1	Clear Creek at Alabama Highway 13/F	Fayette	N 33° 39.042' W 87° 39.106'
ClC2	Clear Creek at County Rd. 93/F	Fayette	N 33° 40.711' W 87° 39.580'
ClC3	Clear Creek at Lowery Road/F	Fayette	N 33° 41.372' W 87° 39.822'
ClC4	Clear Creek downstream of Bays Lake/F	Fayette	N 33° 41.599' W 87° 39.173'
ClC5	Clear Creek at Clear Creek Road/F	Fayette	N 33° 44.175' W 87° 40.376'
CnC1	Cane Creek at County Road 63/F	Fayette	N 33° 41.944' W 87° 35.331'
CpC1	Cripple Creek at County Road 38/T	Tuscaloosa	N 33° 29.572' W 87° 33.739'
CpC2	Cripple Creek at mouth of Johnson Creek/T	Tuscaloosa	N 33° 30.516' W 87° 32.406'
CrC1	Cedar Creek near North River confluence/T	Tuscaloosa	N 33° 34.833' W 87° 37.285'
DC1	Deadwood Creek near U.S. Hwy. 43/F	Fayette	N 33° 39.599' W 87° 39.448'
GC1	George Creek at County Road 63/F	Fayette	N 33° 44.835' W 87° 35.446'
HC1	Hendon Creek at County Road 63/F	Fayette	N 33° 46.507' W 87° 36.219'

[1] Station numbers correspond to those on figures 1 and 2.

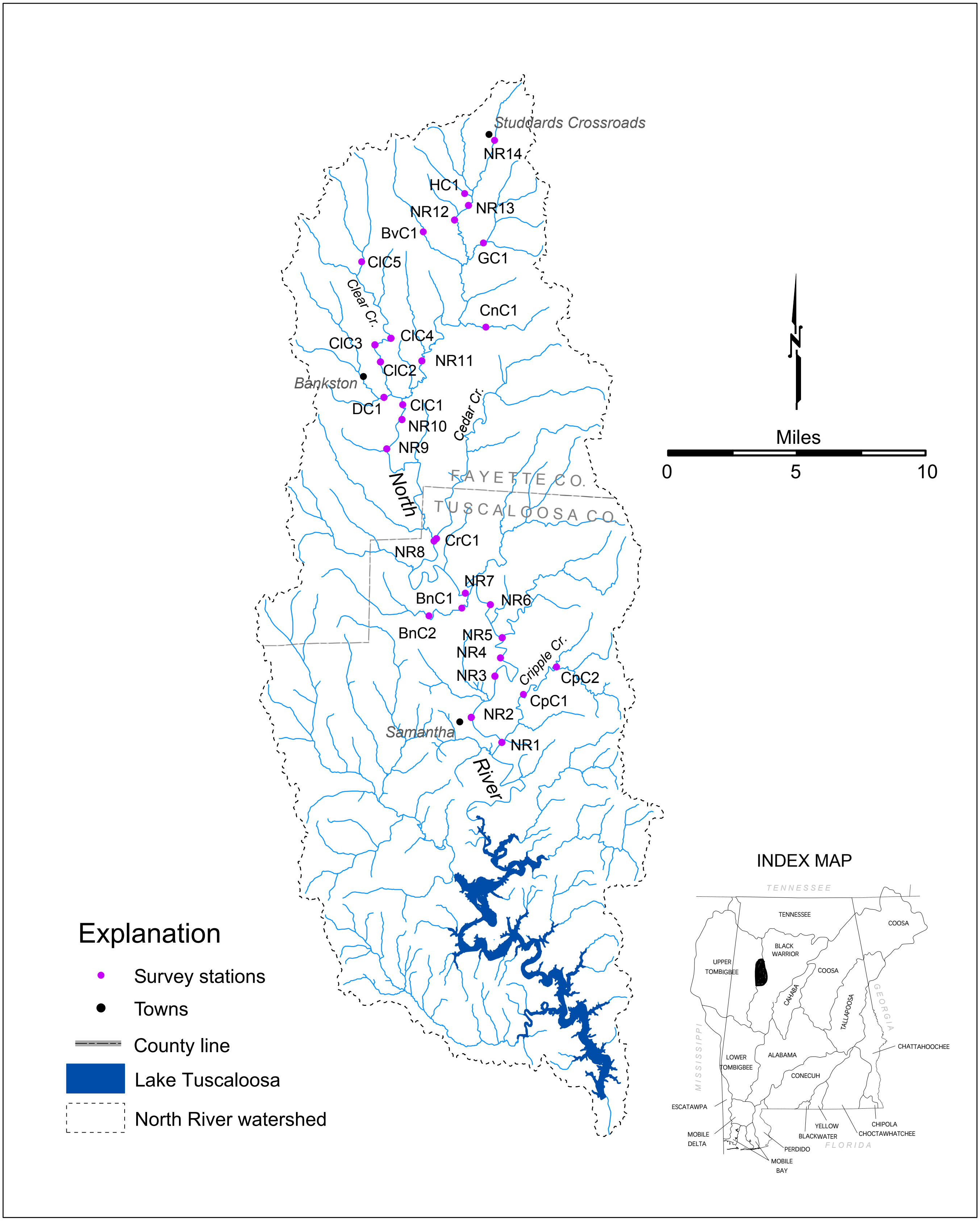

Figure 1. Survey stations in the North River watershed, 2005 and 2008.

Table 2.—Overview of freshwater mussels collected in the North River system, Alabama, 1991-1993, 1996, and 2005 and 2008.

Species	Conser-vation Status[1]	North River status	
		1991-1993, 1996[2]	2005, 2008
Amblema plicata	P4	A single fresh dead shell was collected at the most downstream North River station	A single weathered dead shell was collected at the same station
Anodontoides radiatus	P2	Not reported	Found live at two main channel and one tributary stations
Elliptio arca	P1	Fresh and weathered dead shells were collected from one North River station and from Cedar Creek near its confluence with North River	Not collected
Elliptio arctata	P1	Fresh and weathered dead shells were collected from three North River stations	Live individuals were collected at two Clear Creek stations
Hamiota perovalis	T, P2	Live individuals were found at two North River stations and fresh or weathered dead at three additional stations	Live individuals were found at two Clear Creek stations and fresh dead at one North River station
Lampsilis ornata	P4	Fresh and weathered dead shells were collected from three North River stations and one each in Cedar and Clear Creeks	Single fresh dead shells were found at one station each in North River and Clear Creek
Lampsilis straminea	P3	This species was collected from nine main channel and four tributary stations	Live individuals were found at several stations in Clear Creek and its tributary Deadwood Creek
Lampsilis teres	P5	One weathered shell was collected from Cedar Creek near its confluence with North River	A live individual was found in Clear Creek
Pleurobema furvum	E, P1	Live individuals were collected at two North River stations and fresh dead at one station	A live individual and a fresh dead shell were found in Clear Creek
Pyganodon grandis	P5	One fresh dead specimen was collected in the upper North River	A weathered dead shell was found in Boone Creek in 2005
Quadrula asperata	P5	Live animals and fresh and weathered dead shells were collected from nine North River stations	Live and fresh dead shells were found at three North River and two Clear Creek stations
Quadrula verrucosa	P4	Live animals were collected at one main channel station and fresh dead shells from six North River stations	Fresh dead shells were found at one North River station and weathered dead at two additional stations
Strophitus subvexus	P3	Live animals were collected at 17 North River and three tributary stations	Live individuals were found at several stations in Clear Creek and two North River stations
Uniomerus tetralasmus	P4	Not reported	One live individual was collected at one upper North River station
Villosa lienosa	P5	Live animals were collected at one North River station and fresh dead or relic at three additional North River and four tributary stations	Live individuals were found at several stations in Clear Creek and at two North River stations
Villosa vibex	P5	Live and fresh dead shells were found at 10 North River and 3 tributary stations	Live individuals were found at several stations in Clear Creek and one North River station

[1] E=federally listed endangered, T=federally listed threatened; Alabama priority conservation ranks follow Mirarchi (2004): P1=Highest Conservation Concern, P2=High Conservation Concern, P3=Moderate Conservation Concern, P4=Low Conservation Concern, P5=Lowest Conservation Concern.

[2] From McGregor and Pierson (1999).

The most abundant species collected during this project either live or fresh dead were *Elliptio arctata* (34 individuals), *Strophitus subvexus* (22 individuals), *Lampsilis straminea* (20 individuals), and *Villosa lienosa* (14 individuals). The most widespread were *S. subvexus* (9 stations), *V. lienosa* (7 stations), and *L. straminea* and *Quadrula asperata* (5 stations each). During the previous study (McGregor and Pierson, 1999) dominant mussels collected were *S. subvexus* (60 individuals), *Quadrula asperata* (37 individuals), *L. straminea* (27 individuals), *Pleurobema furvum* (26 individuals), and *Villosa vibex* (21 individuals). The most widespread were *S. subvexus* (23 stations), *Villosa vibex* (14 stations) and *L. straminea* (13 stations).

One federally listed endangered and one threatened species, *Pleurobema furvum* and *Hamiota perovalis*, respectively, were collected live during sampling in the North River system from 1991 to 1996, and *P. furvum* was the fourth most abundant species among 14 species reported. However, only one live and one fresh dead specimen of *P. furvum* were found during the current study (at one station in Clear Creek), suggesting a sharp decline in abundance. Similarly, *H. perovalis* was found at five stations in the earlier study (13 live or fresh dead) but at only three stations (two in Clear Creek and one in main channel North River) during this study (3 live or fresh dead). *Ptychobranchus greenii*, another federally listed endangered species, which was reported by van der Schalie (1981) to occur in the drainage prior to 1920, was not collected in either study, nor was *Pleurobema hagleri*, another species known from the drainage prior to 1920, which has not been reported in the scientific literature, technical reports, or museum collections in over 30 years and is considered extinct by the USFWS (Hartfield, 1994).

The reasons for the change in dominance and frequency between the studies cannot be determined with certainty, but several explanations are possible. These include changes in habitat quality and availability and sample bias. During the previous study the most diverse and abundant locations were in the North River at the mouth of Cedar Creek, where 39 individuals among 8 species were collected. During this project only one weathered dead shell was found there. A station in the North River just upstream of Cedar Creek and another in the lower reach of Cedar Creek were the next most diverse locations, each with 7 species. No species were found during this project in Cedar Creek. The additional North River reach was not sampled during this study. Sample bias could also account for the discrepancy in abundance and distribution. During this project numerous *Elliptio arctata* were found in a unique niche preferred by that species, under large slab rocks, many of which were flipped over (19 were found under one rock). Since no discussion of sampling methodology was offered by McGregor and Pierson (1999) it is unknown if that sampling technique was employed and it is possible that *E. arctata* may have been underrepresented.

Two species collected during this project were not reported by McGregor and Pierson (1999)—*Anodontoides radiatus* and *Uniomerus tetralasmus*—and one species reported during the previous study, *Elliptio arca*, was not collected during this study. *Anodontoides radiatus* strongly resembles *Strophitus subvexus*, and distinguishing the two can be problematic. In the Mobile Basin, *A. radiatus* is widespread downstream of the Fall Line with some populations upstream of the Fall Line, while *S. subvexus* is now generally considered to be restricted to the Black Warrior and Tombigbee River drainages, usually downstream of the Fall Line, but with some populations upstream (Williams and others, 2008). It is possible that some individuals reported as *S. subvexus* in the previous study were misidentified. In the Mobile Basin *Uniomerus tetralasmus* is generally restricted to downstream of the Fall Line, with some records from the upper Coosa River system. It is found in headwater streams, ponds, and floodplain lakes, may be locally abundant, and can withstand extended periods of dewatering (Williams and others, 2008). It may have been merely overlooked during the previous study. This collection represents a new tributary record for the species. *Elliptio arca* strongly resembles *Elliptio arctata*. Only one fresh dead and two weathered dead shells of *E. arca* were reported by McGregor and Pierson (1999) and may have been misidentified. However, *E. arca* has been documented from the North River system (Williams and others, 2008) and their limited presence in the previous study and absence during this study may document a decline within the system.

A variety of human activities in the North River drainage have contributed to siltation of the main channel and tributaries. The substrate in pools and in some riffle areas was often dominated by a dense layer of coarse sand covered with a fine layer of silt. Live mussels were usually found in areas of slow to moderate current in relatively silt-free sand or gravel substrate.

SEDIMENT SAMPLING

On January 28, 2008, composite bed sediment samples were collected from four stations in the North River system, including three in the main channel; at Fayette County Road 30 bridge near Berry (NR11), at Tuscaloosa County Road 55 bridge (Whittson Bridge) (NR7), and at Tuscaloosa County Road 38 bridge near Samantha (NR2); and one in Clear Creek at Alabama Highway 13 bridge near Bankston (ClC1) (fig. 2; appendix). These samples were transported in a chilled cooler to the Geological Survey of Alabama Geochemistry Lab for analysis (table 3). While a large assortment of parameters were analyzed in North River sediments during this study (appendix), this discussion will be limited to selected trace metals that, based on the literature, have the most potential to affect existing and future mussel faunas. The values reported here were determined from one-time grab samples and should not be relied upon as absolute indicators of a persistent or widespread presence in the system and provide no information on sources of contamination.

As noted before, cadmium, chromium, copper, mercury, nickel, and zinc are the metals most toxic to freshwater mussels, with mercury, copper, and cadmium having the most toxicity. Furthermore, it is apparent that metals in shallow bed sediments are more toxic to juvenile stage mussels, as they tend to receive more of their nourishment from interstitial waters and therefore have a higher likelihood of exposure to toxins than adults, which generally receive their nourishment from the water column. This is an important factor should attempts be made to introduce hatchery reared or transplanted mussels to the system.

Comparison of the results of this study to the literature suggests that the values recorded from North River are within a normal range and would not affect any life stages of mussels. However, it must be reiterated that these values were obtained from one-time grab samples from four stations within a large system and cannot be expected to represent the system as a whole. The minimum and maximum values encountered (at any of the stations sampled) are compared to other systems in the general vicinity whose mussel populations are well known and where recent sediment chemistry data are available (table 3).

Values of major elements and trace elements for the samples collected during this study are presented in table 3, along with values determined from sediment samples collected for unrelated projects in other stream systems with recognized valuable mussel faunas. The other systems include the Buttahatchee River (one sample) (McGregor and others, 2006), the Bear Creek system of the Tennessee Valley (one sample collected at each of 10 stations) (McGregor, 2003), the Black Warrior River (23 samples from eight station in the Oliver Pool near Tuscaloosa) (unpublished data, Geological Survey of Alabama), and the upper Cahaba River system (18 samples from six stations) (Shepard and others, 1994).

Chromium was detected in at least some samples from every stream system sampled, with the value from the Buttahatchee sample near the lower end of the range, at 1.5 mg/kg. The

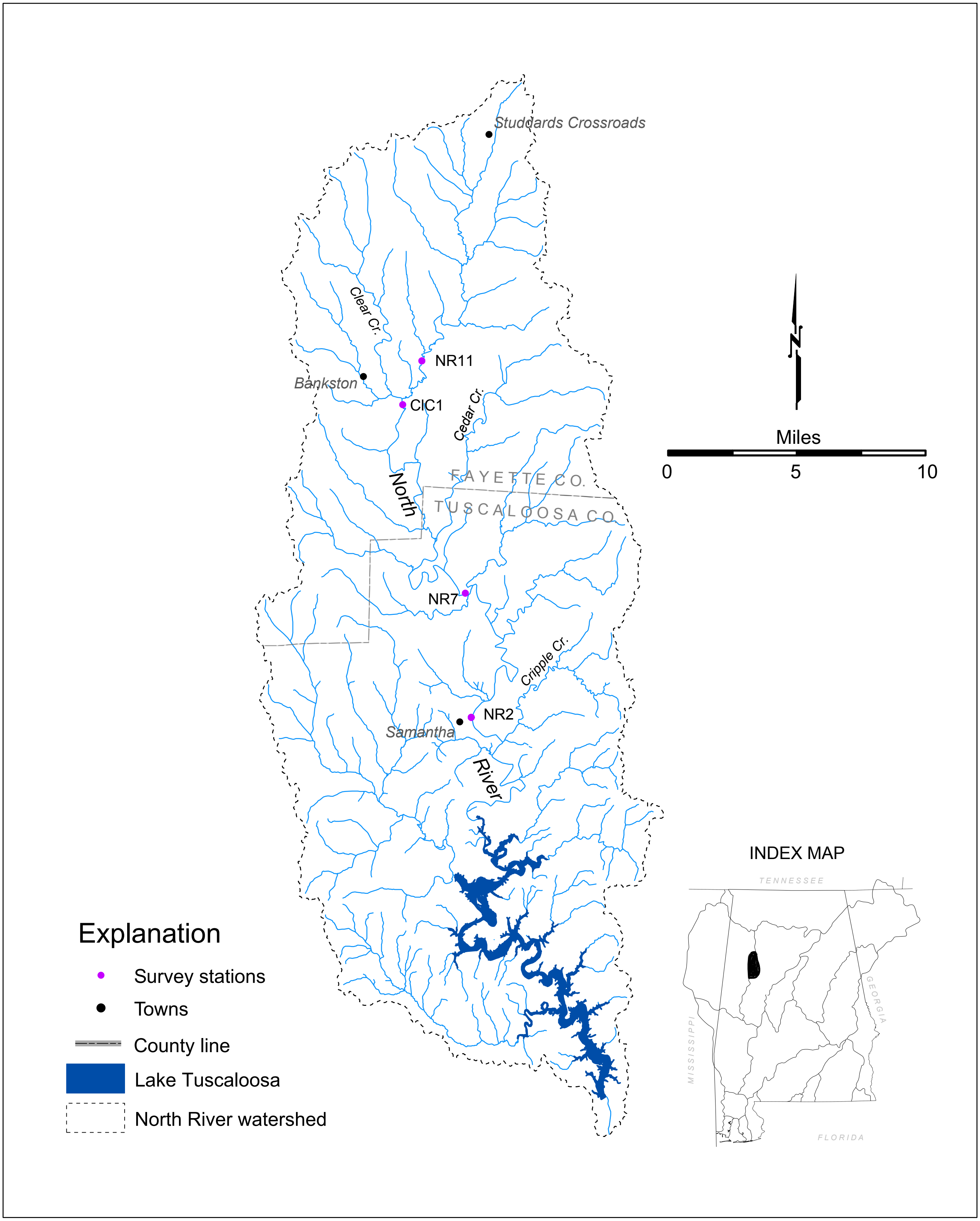

Figure 2. Sediment sampling stations in the North River watershed, 2008.

Table 3.—Comparison of sediment toxicity values from the North River with those of other streams.

	North River[1]		Butta-hatchee River[2]	Bear Creek[3]		Black Warrior River[4]		Cahaba River[5]	
Major Elements (mg/kg)	min	max	BR1	min	max	min	max	min	max
Bromide	0	0	<.6	<.7	<.7	<.5	<.5	--	--
Calcium	192	1,060	156	66.7	81,000	110	2,110	465	42,600
Chloride	0	41.5	<.4	0.882	10.5	10.7	38.5	<.4	<.4
Cyanide	0	0	0.09	<.06	<.06	<.1	0.55	--	--
Fluoride	0	0.11	<.06	<.25	0.514	<.2	8.75	<.2	34.4
Magnesium	313	1,060	92	26.3	2370	106	1970	231	12,600
Ammonia (as N)	11.8	34.1	22.7	<.4	7.43	0.98	27.8	1	48.6
Total Kjeldahl Nitrogen	468	757	695	34.6	804	112	4,300	337	7,300
Total Nitrate-Nitrite (as N)	0.19	0.49	0.45	<.06	17.5	0.65	11.2	0.8	3.5
Total Phosphorus (as P)	0	0	70	27	156	41.7	641	118	477
Orthophosphate	<1	<1	<1	<.4	2.24	<.5	1.61	<.5	11
Potassium	147	668	75	<40	276	<60	1,200	119	1,260
Sodium	8	90	6	<6	48	<6	182	<6	107
Sulfate	0	195	4.99	4.11	49.5	7.08	356	<.4	28.6
Trace Elements (mg/kg)									
Aluminum	3,140	6,510	1,290	538	6,390	597	16,600	1,680	9,340
Antimony	0	0.34	<.2	<.2	<.2	<.2	0.965	--	--
Arsenic	0	3.92	1.57	0.54	4.9	0.318	22.7	2.58	12.3
Barium	30.1	73	19.8	6.32	52.6	7.64	156	21.7	119
Beryllium	0.2	0.5	0.21	<.1	0.57	<.05	1.1	0.16	2.55
Cadmium	0	0.55	<.3	<.4	<.4	<.4	2.11	<.4	2.07
Chromium	5.9	12	1.5	2.2	19.2	<2	25	5	49.1
Cobalt	2.9	7.4	2.5	<.7	8.1	1.34	30.3	1.9	17.7
Copper	3.3	8.4	1.3	<.8	5.2	0.975	26.4	2.28	9.29
Iron	6,000	13,700	4,410	1,700	12,800	473	29,900	6,620	27,800
Lead	3.74	16.2	1.88	<.1	15	0.347	21	<.1	4.06
Lithium	2.2	8.4	<.8	<.5	2.37	<1	23.9	<1	8.6
Manganese	176	410	156	35.3	615	61.8	2130	240	2,580
Mercury	0	0	<.006	<.006	0.131	0.0066	0.195	0.0103	0.0619
Molybdenum	0	0	<2	<2	<2	<7	11.5	<7	14.4
Nickel	4	10.4	3.1	<1	6.1	<1	39.5	5	68.7
Selenium	0	0.45	<.3	<.3	<.3	<.3	0.922	<.3	0.49
Silver	0	0	<1	<1	<1	<2	<2	<2	<2
Strontium	2.85	9.45	1.74	0.38	127	1.02	17.3	1.85	21.6
Thallium	0	12.2	<.2	<.2	<.2	<.3	0.44	--	--
Vanadium	5.7	16.5	4.15	1.76	20.2	<.6	32.9	5.27	31.6
Zinc	19.2	35.1	25.7	5.12	43.4	8.19	155	14.9	192

[1] North River - 1 sample from each of four stations.
[2] Buttahatchee River - 1 sample from 1 station (McGregor and others, 2006).
[3] Bear Creek - 10 samples from 10 stations in the Bear Creek system (McGregor, 2003).
[4] Black Warrior River - 23 samples from 8 stations in the Oliver Pool (unpublished GSA data, 1992-93).
[5] Cahaba River - 18 samples from 6 stations in the upper Cahaba River system (Shepard and others, 1994).

high value among these systems was 49.1 mg/kg in the Cahaba River, with highs of 25 and 19.2 in the Black Warrior River and Bear Creek studies, respectively, and 12 mg/kg in the North River system. Keller and Zam (1991) reported the 48-hour (48h) LC_{50} (lethal concentration to 50 percent of test organisms) of chromium, nickel, and mercury exposures to juvenile *Anodonta imbecillis* in soft water (hardness 40-80 mg/L $CaCO_3$) ranged from 216 to 295 µg/L, and that LC_{50}s increased 8 to 200 percent with exposure to moderately hard water (80-100 mg/L $CaCO_3$). Keller (1993) reported that LC_{50}s of *Anodonta imbecillis* in an effluent containing 6.4 mg/L chromium decreased between 48h and 96h tests.

Copper was also detected in each system, and the lowest value recorded was from the Bear Creek system (<0.8 mg/kg). Highest values were reported from the Black Warrior River (26.4 mg/kg). The high value in North River was 8.4 mg/kg. Keller and Zam (1991) reported the 48h LC_{50} of copper to juvenile *Anodonta imbecillis* to be 171 µg/L with the 96h LC_{50} reduced to 86 µg/L. Foster and Bates (1978) reported *Quadrula quadrula* in the Muskingum River, Michigan that were exposed to copper-containing industrial outfall accumulated to a lethal level of 20.64 µg copper per gram wet weight, or 10 times the background level, after only 14 days, with 100 percent mortality. Imlay (1971) similarly reported copper at a concentration of 25 µg/L was lethal to mussels (species not given).

Mercury was not detected in North River and Buttahatchee River samples, but was detected in all other systems, with the highest values found in Black Warrior River (0.195 mg/kg) and Bear Creek (0.131 mg/kg) samples. Reservoir construction is often cited as a cause of elevated mercury concentrations in fish, as naturally occurring mercury in flooded soils is released by bacterial methylation (Bodaly and others, 1984).

Nickel ranged from undetectable levels in Bear Creek and Black Warrior samples to a high of 68.7 mg/kg in the Cahaba River. The value from the Buttahatchee River sediment was again the lowest maximum value recorded (3.1 mg/kg) with North River samples ranging from 4.0-1.0.4 mg/kg. Keller and Zam (1991) reported the 48h LC_{50} of nickel to juvenile *Anodonta imbecillis* at a water hardness of 39 mg/L $CaCO_3$ to be 240 µg/L and in moderately hard water (60 to 120 mg/L $CaCO_3$) to be 471 µg/L.

Zinc was reported from all streams sampled as well, with the highest value of 192 mg/kg reported from the Cahaba River. The value from the Buttahatchee was the lowest maximum value recorded (35.1 mg/kg), with Bear Creek yielding the lowest (5.12 mg/kg) minimum value.

North River zinc values ranged from 19.2 to 35.1 mg/kg. Zinc was found to be the least toxic metal tested on *Anodonta imbecillis* juveniles by Keller and Zam (1991). Their results indicated water hardness of 39 mg/L $CaCO_3$ yielded a 48h LC_{50} of 355 µg/L and a 48h LC_{50} of 588 µg/L in moderately hard water (60 to 120 mg/L $CaCO_3$).

RECOMMENDATIONS

Based on the results of this study, and considering the apparent decline in diversity and abundance of many species from the early 1990s to now, we make the following recommendations:

- Further sampling of the mussel fauna should be executed to further refine the current distribution of mussels in the system.
- Stations that currently harbor diverse and abundant mussel populations in the system should be established and monitored periodically to document trends.
- Habitat factors that influence mussel distribution and abundance should be evaluated by such means as land cover/land use mapping, more intensive evaluation of water and sediment quality, rates of sediment loading, and other means as deemed necessary.
- Upon determination of the limiting factors to the population, steps should be taken to ameliorate those factors.
- Long-term monitoring of the system should be enacted to document recovery

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APPENDIX

Summary information for sediment quality analyses from stations in the North River, 2008.

Sediment parameter	Sediment sampling stations				
	LLD[1]	ClC1	NR1	NR7	NR11
Major Elements (mg/kg)					
pH	0.1	5.0	6.8	6.0	5.2
Bromide	0.6	<0.6	<0.6	<0.6	<0.6
Calcium	1.5	192	817	1060	370
Chloride	0.4	8.04	41.5	16.0	<0.4
Cyanide	0.08	<0.08	<0.08	<0.08	<0.08
Fluoride	0.06	<0.06	<0.06	0.11	<0.06
Magnesium	6	410	313	1,060	895
Ammonia (as N)	0.2	15.9	34.1	27.9	11.8
Total Kjeldahl Nitrogen	20	757	487	537	468
NOx as N	0.06	0.488	0.225	0.188	0.314
Total Phosphorus (as P)	9	98	98	136	160
Orthophosphate	1	<1	<1	<1	<1
Potassium	50	262	147	381	668
Sodium	5	8	33	90	22
Sulfate	0.8	18.5	195	137	<0.8
Trace Elements (mg/kg)					
Aluminum	5	3,140	3,800	5,170	6,510
Antimony	0.2	<0.2	<0.2	<0.2	0.34
Arsenic	0.3	2.71	<0.3	3.92	3.89
Barium	0.1	30.1	37.7	44.4	73.0
Beryllium	0.04	0.3	0.2	0.3	0.5
Cadmium	0.3	0.46	<0.3	0.55	0.52
Chromium	0.8	5.9	6.9	9.0	12.0
Cobalt	1	2.9	3.1	5.6	7.4
Copper	0.5	4.6	3.3	8.4	3.8
Iron	0.4	6,000	6,750	9,320	13,700
Lead	0.1	3.74	6.16	16.2	7.31
Lithium	0.6	2.7	2.2	5.3	8.4
Manganese	0.08	176	375	375	410
Mercury	0.08	<0.08	<0.08	<0.08	<0.08
Molybdenum	2	<2	<2	<2	<2
Nickel	0.3	4.2	4.0	7.8	10.4
Selenium	0.3	<0.3	0.45	<0.3	<0.3
Silver	0.02	<0.02	<0.02	<0.02	<0.02
Strontium	0.05	2.85	9.45	6.19	5.23
Thallium	2	6.0	<2	<2	12.2
Vanadium	1	5.74	5.68	9.12	16.50
Zinc	0.4	19.2	25.7	26.5	35.1

[1] LLD - lower limit of detection

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