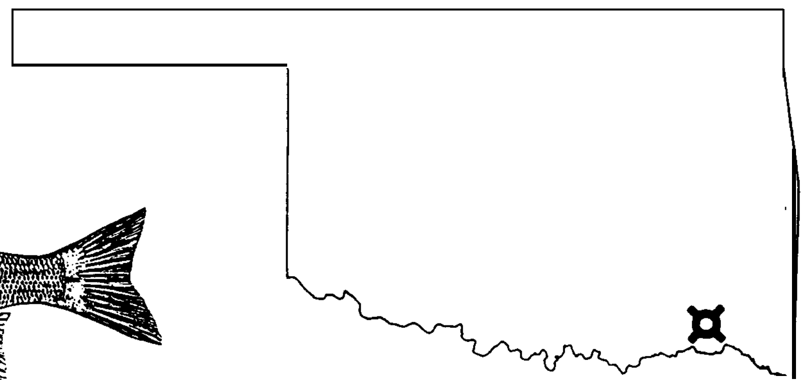
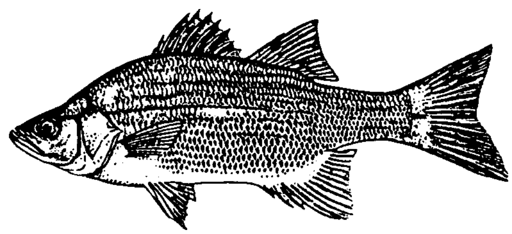
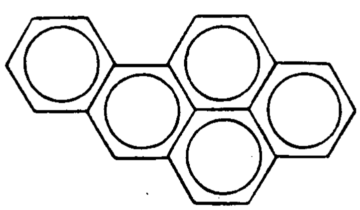
U.S. FISH AND WILDLIFE SERVICE, REGION 2
ENVIRONMENTAL QUALITY PROGRAM

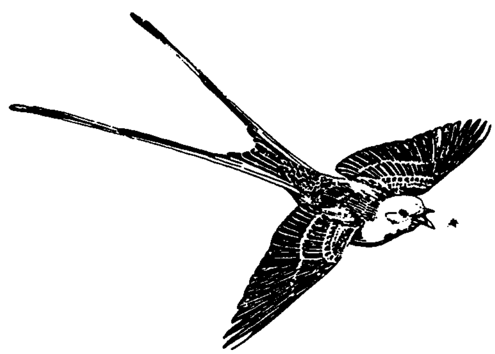
CONCENTRATIONS OF SELECTED ELEMENTS IN THE KIAMICHI RIVER ABOVE HUGO RESERVOIR

by
Dan B. Martin









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CONCENTRATIONS OF SELECTED ELEMENTS

in

THE KIAMICHI RIVER

ABOVE HUGO RESERVOIR

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ABSTRACT

Bulk element concentrations in soil collected from undisturbed forested sites throughout the Kiamichi River watershed above Hugo Reservoir were significantly higher in aluminum, arsenic, chromium, iron, lead, manganese and zinc than Kiamichi River sediment. There was no difference between soil and sediment with respect to copper, magnesium and nickel; cadmium, selenium and mercury could not be compared due to lack of detection in a sufficient number of samples. Geochemical normalization of soil and sediment data revealed that copper, magnesium, manganese and nickel were apparently enriched in sediment, whereas arsenic and lead were depleted. There was no difference with respect to chromium, iron or zinc. A comparison of element concentrations in the Kiamichi River sediment with guidelines suggested for the protection of benthic organisms indicated that sediments in this section of the river are not likely to be harmful.

Significant differences in the concentration of arsenic, cadmium, chromium, iron, lead, magnesium and zinc were found between shoots and roots of water willow; whereas concentrations of aluminum, copper, manganese and nickel were similar in the two types of tissue. Mercury and selenium were not detected in plant tissues. Water willow did not bioaccumulate elements from sediments.

Measurable concentrations of aluminum, arsenic, cadmium, chromium, copper, iron, magnesium, manganese, mercury, selenium and zinc were found in all three species of mussels. In general, intraspecific variation for each element was low compared to soil, sediment and water willow tissues. Significant interspecific differences were found for all elements except aluminum, magnesium and mercury. Bioaccumulation was greater in mussels than in plants. Element concentrations in mussels from the Kiamichi River were comparable to those from non-contaminated areas.

A base monitoring program, using the mussel Amblema plicata is recommended for determining long-term changes in element concentrations in the Kiamichi River ecosystem. Samples collected every ten years at seven different sites along the river could be analyzed by the same methods employed in this study at a total cost of approximately $4.000. Resource managers could undertake appropriate, more specific measures to determine the location, cause and possible effects in the event of significant increases.

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ACKNOWLEDGEMENTS

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INTRODUCTION

The U. S. Fish and Wildlife Service (FWS) listed the Ouachita rock-pocketbook (Arkansia wheeleri) as an endangered species in 1991. The only known viable population of this freshwater mussel is located in southeast Oklahoma, in the Kiamichi River above Hugo Reservoir.

Mussel communities in the Kiamichi River are substantially more diverse than those found in other rivers of the region, and contain a high proportion of rare species (Oklahoma Biological Survey 1972). It is common to find 15 species in a mussel bed, and some beds have as many as 27 co-occurring species (Aquatic Life Consultants 1978). In contrast to most rivers in the eastern United States, the Kiamichi appears to have lost very few mussel species since the beginning of the century, when it was first surveyed.

Several activities involving land-use and water management pose potential problems for the survival of the unique mussel assemblages in the Kiamichi River. Large-scale water sales from the Kiamichi watershed to metropolitan areas in Texas could affect water quantity in the river. Additional impoundments would further alter the natural hydrologic regime. Proliferation of high density poultry and swine feeding operations, removal of the riparian border, and increased clear-cut logging could impact water quality.

As part of a broader effort to better understand the various factors that may affect this unique resource, FWS conducted a survey of selected elements in soils, benthic sediments, aquatic plants and mussels from the Kiamichi River and it's watershed in 1993 and 1994. The objective of this survey was to provide a baseline for future reference. The purpose of this report is to summarize the data from that survey and suggest how it can be used as a basis for a long-term monitoring program.

DESCRIPTION OF THE STUDY AREA

The Kiamichi River originates in the Ouachita and Kiamichi Mountains of southeast Oklahoma, near the Arkansas border (Figure 1). From its source, the river flows westerly between the Ouachita Mountains on the north and the Kiamichi Mountains on the south, to near the town of Clayton. There the river gradually turns and flows south by southeast to its confluence with the Red River. Channel slope varies from 20 m/km at the source to less than 0.3 m/km at the headwaters of Hugo Reservoir (Echelle and Schnell 1976). During most of the year, the river above Hugo Reservoir consists of long, clear pools and extended riffles. The bottom is covered with sand, gravel and large sandstone rocks. Below the mouth of Jackfork Creek, the river is influenced by discharges from Sardis Reservoir. Turbidity often increases and water levels fluctuate more irregularly.

The crescent-shaped Kiamichi River Basin is 175 km long, 8 to 50 km wide, and contains approximately 4,800 sq km. Soils are thin and poorly developed, often on steep, stony, mountain

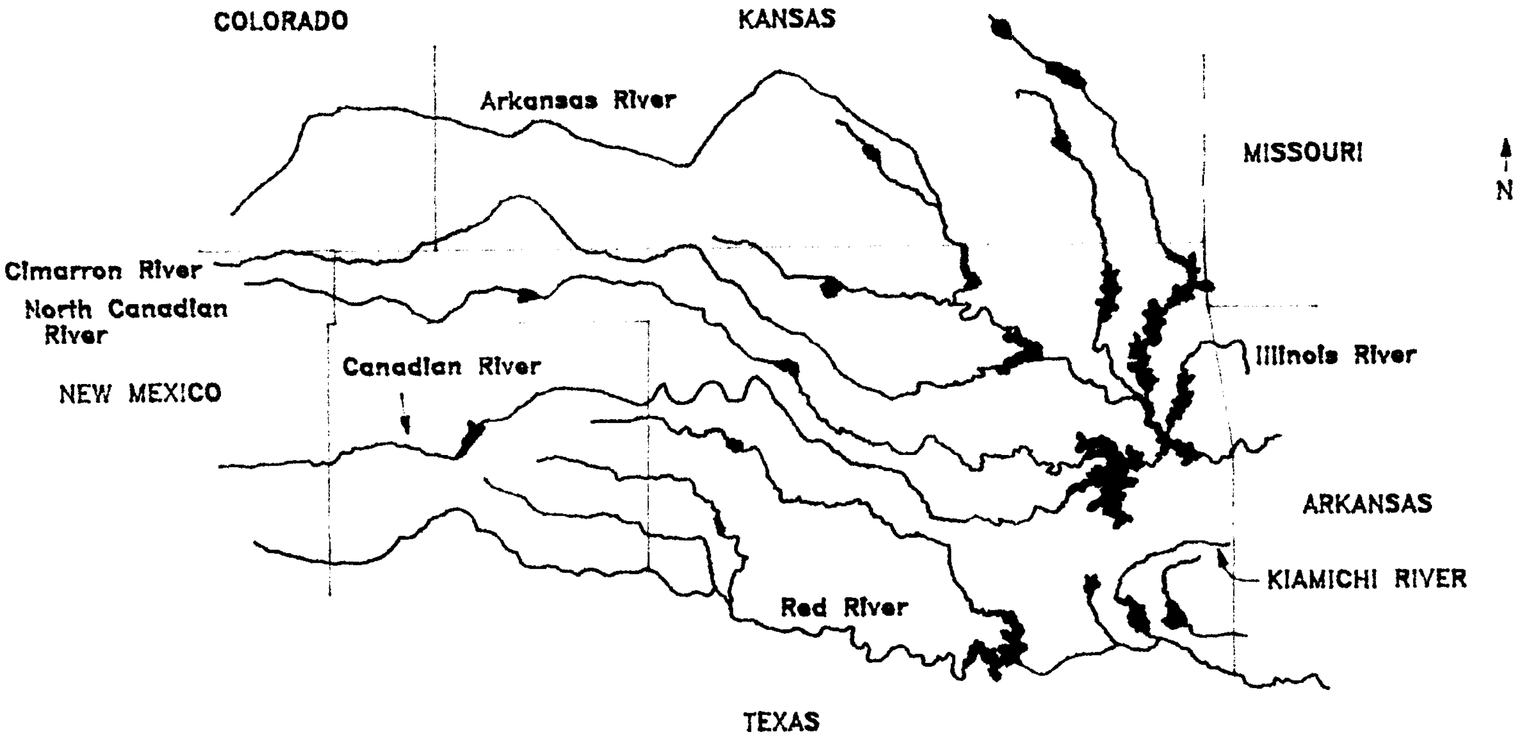

Figure 1. Location of the Kiamichi River in Oklahoma.

slopes. There is little cultivation. Vegetative cover in the watershed is a patchwork of short-leaf and loblolly pine, oak, pastureland, and diverse bottomland communities in various stages of maturity (Vaughn et al. 1993). The study area lies within Omernik's (1987) Ouachita Mountains Ecoregion.

METHODS

Sample Collection

Soil samples were collected in September 1993 from thirteen sites located throughout the Kiamichi River watershed above Hugo Reservoir (Figure 2). Sampling sites were located on both sides of the river, at access points near where sediment samples were taken. The purpose of the soil samples was to characterize the parent material from whence benthic sediments in the Kiamichi River are derived. Each soil sample was taken at an undisturbed, forested site at an elevation at least 100 meters above the adjacent river bed. For each sample, the layer of unincorporated organic litter was removed from the soil surface, and the upper 5 cm of underlying soil was placed directly into a chemically precleaned 1-liter plastic jar. Samples were refrigerated from collection until laboratory analyses were completed.

Duplicate sediment samples were collected in September 1993 from thirteen sites along the Kiamichi River between the source and Hugo Reservoir (Figure 2). The purpose of the sediment samples was to characterize material from depositional areas in the river. In general, it was difficult to locate areas where significant accumulations of material had been deposited. Therefore, sediment samples consisted of the finest material that could be found at a given location. These materials usually appeared as thin deposits, only a few millimeters in depth, in backwater areas or around rocks and snags. Often, 50 to 100 meters of river had to be searched to obtain a sample. Sediment samples were collected with a stainless steel spoon, placed into chemically precleaned 1-liter plastic jars, and refrigerated until they were analyzed.

Samples of water willow (Justica americana) were collected in August 1994 from five sites above Hugo Reservoir (Figure 3). Entire plants were removed from inundated substrate and placed directly into plastic bags. Later, shoots and roots of individual air-dried plants were separated, and composite samples of shoots and roots were formed for each site. Seven composite root samples and eight composite shoot samples (at least one each from each site) were submitted for analysis.

Mussel samples were collected in June 1994 from seven sites above Hugo Reservoir (Figure 3). Individual mussels were picked from the substrate and immediately placed on ice. After a site had been sampled, the soft parts of each mussel were removed from the shell by opening it with a stainless steel knife, and scraping the contents onto a piece of aluminum foil with the knife and a stainless steel spoon. Three replicate composites of soft tissue (consisting of 4 to 10 individuals) were formed for each species collected at a given site, wrapped in aluminum foil, and frozen until analysis. Threeridge (Amblema plicata) was collected from all seven stations; pimpleback (Quadrula

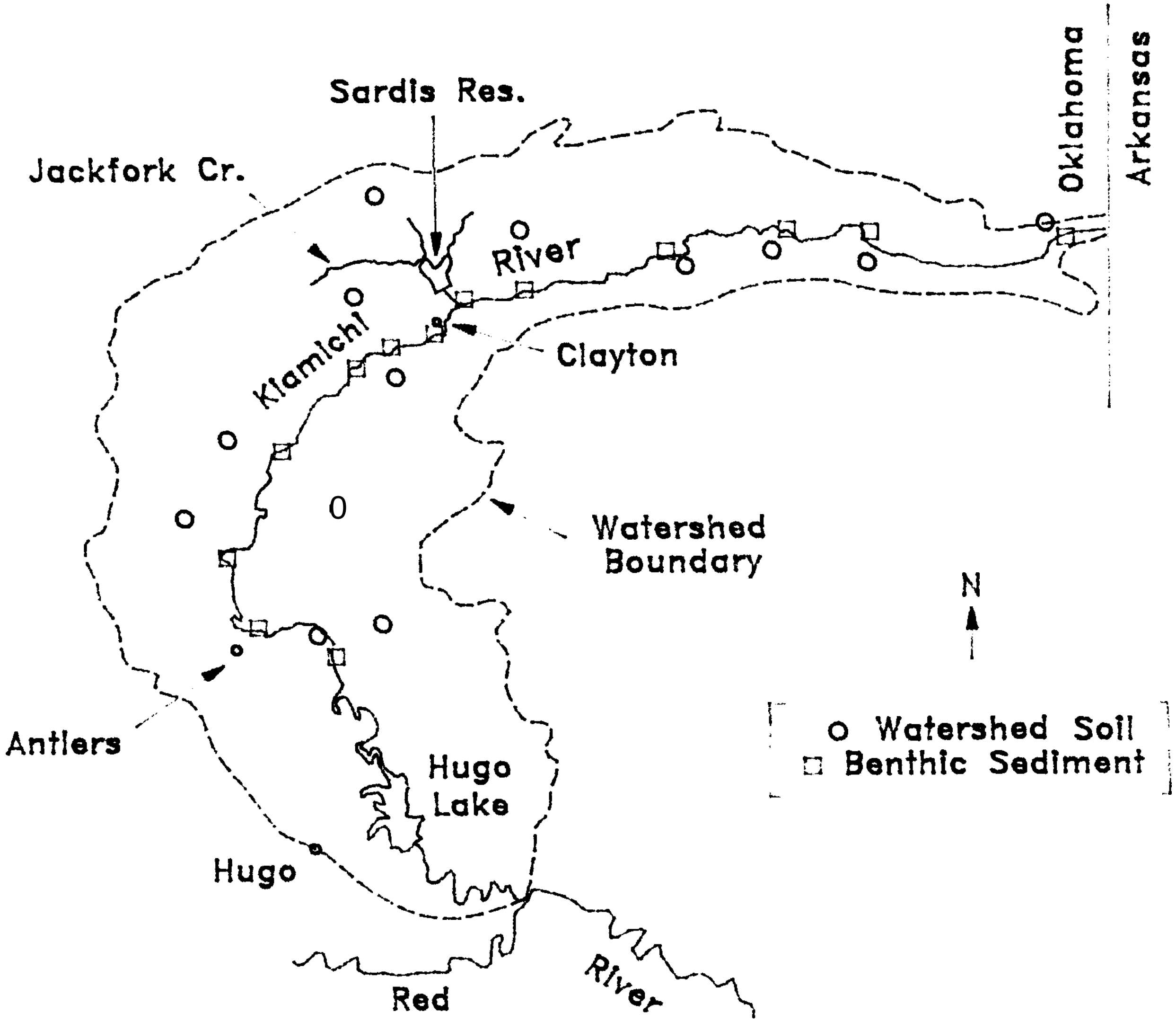

Figure 2. The Kiamichi River watershed showing locations of soil and sediment samples.

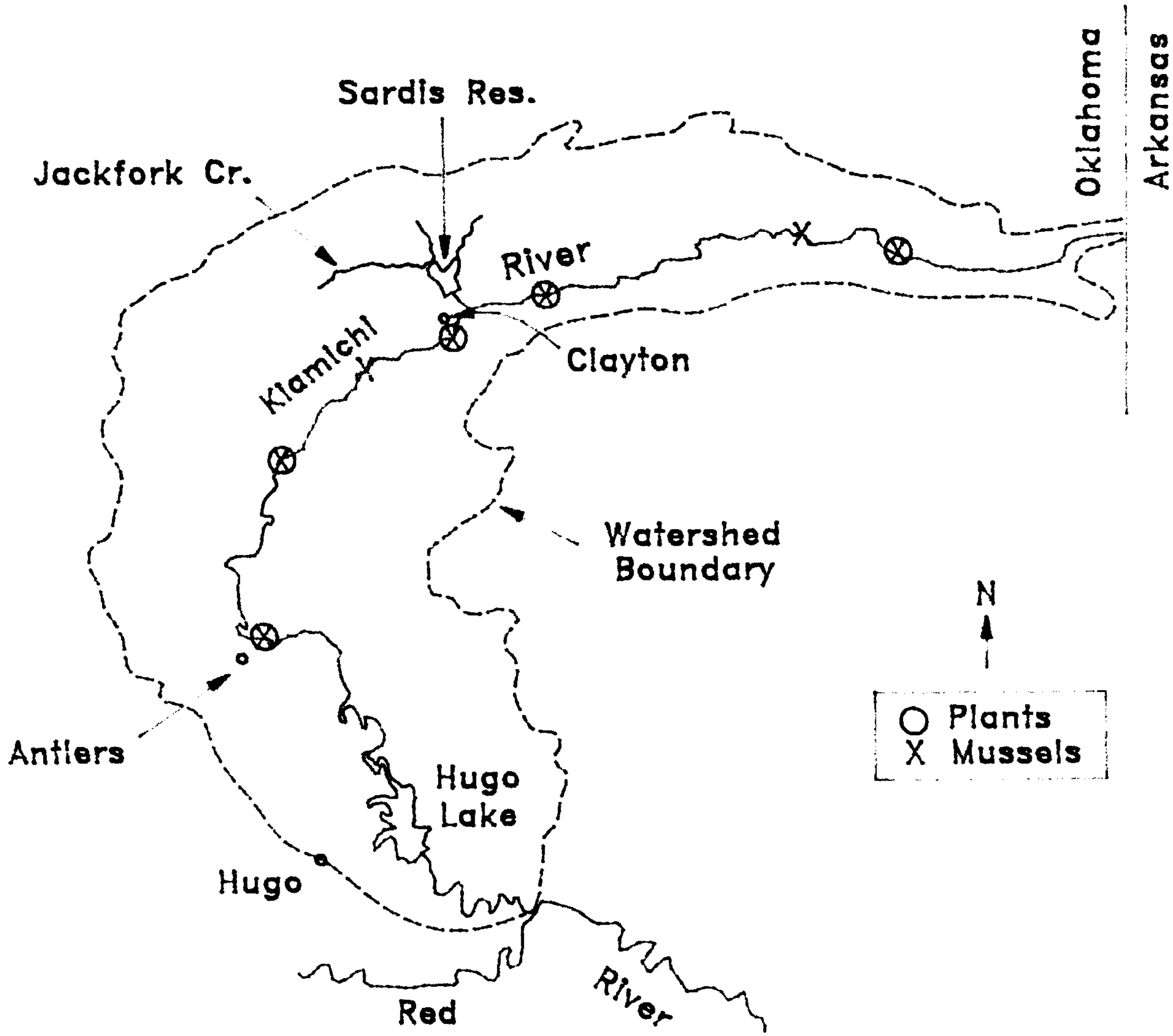

Figure 3. Locations of plant and mussel samples taken from the Kiamichi River.

pustulosa) and pistolgrip (Tritogonia verrucosa) were taken from four sites. Common and scientific names for mussels are according to Harris and Gordon (1990).

Sample Analysis

All samples were analyzed in the year that they were collected by Hazleton Environmental Services, Inc. The Patuxent Analytical Control Facility maintains a rigorous program of methods standardization and quality assurance/quality control (QA/QC) assessment for all FWS contract laboratories, including Hazleton. Procedural blanks, duplicates, spiked samples, and analysis of standard reference materials were used routinely with each batch of samples analyzed to evaluate and maintain QA/QC.

Aluminum, cadmium, chromium, copper, iron, lead, magnesium, manganese, nickel and zinc were determined by inductively coupled plasma (ICP) emission spectroscopy. Mercury was determined by cold vapor atomic absorption (CVAA). Arsenic and selenium were determined by graphite furnace atomic absorption (GFAA). Nitric acid digestion preceded the ICP and GFAA determinations. A mixture of nitric and sulfuric acids was used for digestion prior to mercury analysis. Elemental analyses in soil and sediment were accompanied by determinations of total organic carbon (TOC) and grain size. All results are expressed on a dry weight basis.

Data Analysis

Statistical treatment of data was performed according to methods found in Steel and Torrie (1960) and/or LeClerg et al. (1962) using SYSTAT software. Means of two independent groups of samples were compared using either a t-test or it's equivalent one-way ANOVA. An ANOVA, combined with Tukey's HSD procedure was used to compare means of three or more independent groups. Linear regression and Pearson's correlation coefficient were used to describe the relation between two variables. Unless specifically noted, all statistical tests were performed on non-transformed data. Statistical significance is expressed at probabilities equal to or less than 0.05.

RESULTS AND DISCUSSION

Soil and Sediment

Eleven elements (aluminum, arsenic, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel and zinc) were always present at detectable concentrations in soil samples (Table 1). Except for manganese, basin-wide concentrations of each element varied by less than an order

Table 1. Concentrations of selected elements in soil samples collected from the Kiamichi River watershed in 1993 (n=13). The ratio of each element to aluminum, and clay-normalized concentrations are also shown.

Element	Bulk Analysis (ppm)			Ratio: Aluminum/Element			Clay Normalized (ppm)		
	Mean	C.V.[1]	Range	Mean	C.V.	Range	Mean	C.V.	Range
Aluminum	8119	43%	4148-15875	1.0	0%	1.0-1.0	63815	31%	40292-102162
Arsenic	3.5	51%	1.5-7.9	2488	27%	1591-3689	27	34%	12-40
Cadmium	--[2]	--	<0.20-0.31	--	--	--	--	--	--
Chromium	13	51%	5.2-28	661	29%	348-1081	102	35%	58-167
Copper	4.6	51%	1.8-l 1	1888	26%	1218-2959	35	36%	20-66
Iron	14097	51%	4682-32250	0.63	34%	0.42-1.2	107385	32%	52022-171378
Lead	15	31%	7.6-26	547	38%	306-1089	125	32%	67-190
Magnesium	601	40%	346-l 136	14	24%	8.8-22	4887	36%	2205-7927
Manganese	851	150%	25-3689	59	125%	2.2-225	7844	163%	241-40989
Mercury	0.04	54%	0.01-0.08	288703	93%	74829-1080200	0.36	62%	0.04-0.78
Nickel	8.8	61%	2.3-18	1144	50%	480-2445	73	69%	23-189
Selenium	--[3]	--	<0.30-0.92	--	--	--	--	--	--
Zinc	28	44%	14-49	301	28%	181-491	233	48%	100-500
	(percent)								
TOC	6.2	26%	3.6-8.6						
Clay	14	61%	9-39						
Silt	28	42%	9-45						
Sand	58	25%	38-82						

[1]C.V. - Coefficient of Variation (Mean/Standard Deviation)
*Detectable concentrations of cadmium occurred in only 38% of the samples
'Detectable concentrations of selenium occurred in only 54% of the samples

of magnitude, with coefficients of variation ranging from 31% (lead) to 61% (nickel). Manganese concentrations spanned more than two orders of magnitude, with a coefficient of variation of 150%. Detectable concentrations of cadmium (> 0.20 ppm) and selenium (> 0.30 ppm) were found in 38% and 54% of the soil samples, respectively.

Ten elements (aluminum, arsenic, chromium, copper, iron, lead, magnesium, manganese, nickel and zinc) were detected in all sediment samples (Table 2). Concentrations of most elements except manganese, varied by about an order of magnitude, with coefficients of variation ranging from 39% (chromium) to 67% (magnesium). As in the soil samples, manganese was the most variable element in sediment. None of the sediment samples contained detectable levels of cadmium (> 0.40 ppm) or selenium (> 0.40 ppm). Mercury was found in 50% of the sediment samples at concentrations up to 0.09 ppm.

The statistical comparison of bulk element concentrations in watershed soil versus riverine sediment indicated that: (1) soil was significantly higher than sediment in aluminum, arsenic, chromium, iron, lead, manganese and zinc; and (2) copper, magnesium and nickel were not significantly different in soil and sediment. No element was higher in sediment than in soil.

Bulk element concentrations in soil and/or sediment from the same watershed are often directly related to the texture of the samples, due to (1) the chemical similarity of the geologic parent material within the watershed, and (2) the affinity of individual elements for the finest grain-size fractions (de Groot, 1995). In this study, total organic carbon (TOC), clay and silt were all significantly higher in soil than in sediment (Tables 1 and 2). Perhaps, bulk concentrations of elements in the two media were a reflection of textural differences. With this in mind, correlation coefficients between the concentration of each element and the percent composition of TOC and each grain-size fraction (sand, silt, clay) were calculated for soil and sediment. The highest correlation for each element in soil was always obtained in relation to the clay fraction, although correlations for four of the elements (manganese, mercury, nickel and zinc) were not significant (Table 3). In contrast, the highest correlations in sediment were always obtained with TOC, and only one of these (manganese) was not significant. Despite the fact that clay-normalized (soil) and TOC-normalized (sediment) concentrations reduced the variability with respect to certain elements, neither procedure was used to compare elemental concentrations in soil and sediment for reasons outlined by Hebert and Keenleyside (1995).

Element concentrations in soil and sediment can also be corrected by expressing the concentration of the element as a ratio to some conservative element (such as aluminum) in the same sample (Mudroch and Azcue, 1995). In watershed soil, correlations between various elements and aluminum were similar to those found with clay, with two notable improvements, nickel and zinc (Table 3). In sediment, all of the elements were significantly correlated with aluminum. Therefore, aluminum was used to calculate a ratio for each of the elements in soil and sediment. Overall, variation in aluminum/element ratios was markedly less than bulk analyses for each of the significantly correlated elements (Tables 1 and 2). A comparison of mean aluminum/element ratios in soil and sediment indicated that: (1) arsenic and lead were higher in sediment; (2) copper,

Table 2. Concentrations of selected elements in sediment samples collected from the Kiamichi River in 1993 **(n=26)**. The ratio of each element to aluminum, and total organic carbon-normalized concentrations are also shown.

Element	Bulk Analysis (ppm)			Ratio: **Aluminum/Element**			TOC Normalized (ppm)		
	Mean	C.V.[1]	Range	Mean	C.V.	Range	Mean	C.V.	Range
Aluminum	4948	53%	1293-12291	1.0	0%	1.0-1.0	436646	45%	**141582-**930000
Arsenic	1.7	62%	0.38-4.4	3180	29%	1710-5062	151	58%	3 l-400
Cadmium	--[2]	--	--	--	--	--	--	--	--
Chromium	8.0	39%	3.2-16	597	18%	3 18-768	768	54%	194-197s
Copper	4.1	49%	0.62-8.7	1253	21%	**855-2085**	**355**	46%	130-767
Iron	8211	51%	2677-19003	0.60	20%	0.30-0.84	7623 13	56%	233682-2101250
Lead	4.6	44%	1.4-10	1065	24%	734-1972	427	54%	134-1267
Magnesium	692	67%	148-2060	7.6	15%	**4.6-9.5**	59009	51%	**16636-**131750
Manganese	267	85%	14-1038	27	74%	8.1-92	22832	66%	**1791-**58500
Mercury	--[3]	--	**<0.02-**0.09	--	--	--	--	--	--
Nickel	6.9	57%	2.0-19	722	15%	**475-990**	606	43%	209-1267
Selenium	--[4]	--	--	--	--	--	--	--	--
Zinc	18	52%	5.0-46	274	19%	174-421	1654	58%	**567-5333**
	(percent)								
TOC	1.5	91%	0.3-6.7						
Clay	10	39%	2-20						
Silt	1s	89%	1-47						
Sand	76	20%	40-97						

[1]**C.V. -** Coefficient of Variation (Mean/Standard Deviation)
'Detectable concentrations of cadmium did not occur in any of the samples
[3]**Detectable** concentrations of mercury occurred in only 50% of the samples
[4]**Detectable** concentrations of selenium did not occur in any of the samples

Table 3. Correlation coefficients for each of the elements in soil with aluminum and clay; and in sediment with aluminum and total organic carbon.

	Soil (n = 13)		Sediment (n = 26)	
	Aluminum	Clay	Aluminum	TOC
Aluminum	1.00	0.78*	1.00	0.71*
Arsenic	0.83*	0.85*	0.80*	0.46*
Cadmium	---	---	---	---
Chromium	0.88*	0.82*	0.96*	0.68*
Copper	0.88*	0.85*	0.92*	0.78*
Iron	0.90*	0.88*	0.92*	0.77*
Lead	0.67*	0.72*	0.89*	0.79*
Magnesium	0.85*	0.63*	0.91*	0.56*
Manganese	0.37	-0.10	0.70*	0.34
Mercury	0.15	-0.11	---	---
Nickel	0.74*	0.34	0.96*	0.73*
Selenium	---	---	---	---
Zinc	0.79*	0.47	0.94*	0.78*

* Significant at $p \leq 0.05$

magnesium, manganese and nickel were higher in soil; and, (3) there was no difference in chromium, iron or zinc.

To evaluate the status of contamination in Kiamichi River sediment, comparisons were made between the bulk concentrations summarized in Table 2 and the guidelines of Long and Morgan (1990) and Persaud et al. (1993) shown in Table 4. Only two elements, manganese and nickel, ever exceeded the most conservative of the guidelines shown, and mean values for these two elements were well below any levels of concern. Lemly and Smith (1987) suggested 4 ppm as the level of concern for selenium in sediments. Concentrations were as least an order of magnitude lower in the Kiamichi River. Overall, element concentrations in sediment are not a concern in the section of the river surveyed.

Plants

Eleven elements (aluminum, arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, nickel and zinc) were present at detectable concentrations in all of the water willow root samples (Table 5). Mercury and selenium were never found in roots above their respective detection limits of 0.05 and 1 .0 ppm. Coefficients of variation for elements in roots ranged from 18% (magnesium) to 65% (manganese).

Mean concentrations of arsenic and iron were significantly lower in shoots than roots, while the opposite was true for chromium, magnesium and zinc. Concentrations of aluminum, copper, manganese and nickel were similar in the two types of tissue. Cadmium and lead could not be tested because they were not found in shoots, but it appears that both were substantially higher in roots. Overall, variation for every element except copper was substantially less in shoot tissues (Table 5).

Stewart et al. (1992) reported concentrations of certain elements in the aquatic plant Potamogeton foliosus growing in a contaminated settling basin and in an uncontaminated control site in Tennessee. Mean concentrations of cadmium, chromium, copper, mercury and nickel in pondweed from their control site were very comparable to concentrations of these elements found in water willow tissues from the Kiamichi River. All values for manganese in the Kiamichi plants were substantially higher than the 412 ppm mean for control site plants in Tennessee; however, most samples from the Kiamichi were lower in manganese than the 2,310 ppm mean for plants in the contaminated settling basin. The mean zinc concentration in pondweed from the Tennessee control pond (54 ppm) was higher than anything found in Kiamichi water willow. No evidence could be found to suggest that element concentrations in water willow tissues from the Kiamichi are beyond background.

Bioaccumulation factors (Willford et al. 1987) were calculated for each type of water willow tissue by using the mean concentrations of elements from Tables 2 and 5 (Table 6). Half of the resulting values were equal to or less than 1.0, suggesting that these elements are selectively excluded from plant tissues. Eleven (42%) of the values were between 1.0 and 10, which indicates no positive or negative selectivity. Only two (8%) of the values exceeded 10. There may be a slight

Table 4. Sediment quality guidelines suggested by Long and Morgan (1990) and Persaud et al. (1993). Concentrations in ppm dry weight.

Constituent	Long and Morgan (1990)		Persaud et al. (1993)		
	ER-L[1]	ER-M[2]	Background[3]	Lowest Effect	Severe Effect
Aluminum	---[4]	---	---	---	---
Arsenic	33	85	4.2	6.0	33
Cadmium	5.0	9.0	1.1	0.6	10
Chromium	80	145	31	26	110
Copper	70	390	25	16	110
Iron	---	---	3 1,200	20,000	40,000
Lead	35	110	23	31	250
Magnesium	---	---	---	---	---
Manganese	---	---	400	460	1100
Mercury	0.15	1.3	0.10	0.20	2.0
Nickel	30	50	31	16	75
Selenium	---	---	---	---	---
Zinc	120	270	65	120	820
p,p-DDE	.002	.015	0	.005	19[5]

[1] ER-L - A concentration at the low end of the reported range in which effects had been observed
[2] ER-M - A concentration approximately midway in the range of reported values associated with biological effects
[3] Based on analyses of pre-colonial sediment horizons from the Great Lakes
[4] No data
[5] This value is expressed as ppm TOC. To convert to bulk density value, multiply actual TOC concentration in sediment by 19.

Table 5. Concentrations (ppm) of selected elements in water willow (*Justica americana*) collected from the Kiamichi River in 1994.

Element	Shoots (n = 8)				Roots (n = 7)		
	Mean	C.V.	**Range**	Sig. *t*	Mean	C.V.	Range
Aluminum	688	28%	481-1067	---	478	47%	266-876
Arsenic	1.1	25%	0.83-l.6	*	22	44%	4.7-32
Cadmium	---	---	< 0.40	---	0.42	31%	0.26-0.60
Chromium	1.5	18%	1.3-2.2	*	0.98	43%	0.54-1.6
Copper	4.8	55%	2.4-l 1	---	5.1	25%	3.6-7.5
Iron	1323	19%	1098-1866	*	13449	37%	4146-19009
Lead	---	---	< 3.0	---	3.3	43%	1.5-4.8
Magnesium	9307	11%	8010-10635	*	4436	18%	3413-5595
Manganese	1926	41%	984-2794	---	1767	65%	627-3565
Mercury	---	---	co.10	---	---	---	< 0.05
Nickel	**4.3**	39%	2.2-7.6	---	7.3	53%	4.6-16
Selenium	---	---	< 1.5	---	---	---	< 1.0
zinc	**24**	14%	19-30	*	19	24%	14-27

* Significant at $p \leq 0.05$

Table 6. Bioaccumulation factors (tissue concentration / sediment concentration.) in water willow (*Justica americana*) tissues and in threeridge (*Amblema plicata*), pimpleback (*Quadrula pustulosa*) and pistolgrip (*Tritogonia verrucosa*) collected from the Kiamichi River in 1994.

Element	Water Willow		Mussels		
	Shoots	Roots	Threeridge	Pimpleback	Pistolgrip
Aluminum	0.14	0.10	0.10	0.08	0.09
Arsenic	0.65	13	2.4	1.9	2.1
Cadmium	1.0*	1.0*	5.8*	7.5*	6.2*
Chromium	0.19	0.12	1.1	0.79	0.75
Copper	1.2	1.2	1.8	1.9	3.7
Iron	0.16	1.6	0.74	1.0	0.59
Lead	0.65*	0.72	1.5*	2.2*	0.83*
Magnesium	13	6.4	1.9	1.7	1.7
Manganese	7.2	6.6	39	29	32
Mercury	1.0*	0.50*	6.8*	8.0*	9.7*
Nickel	0.62	1.1	1.2*	7.5*	1.2*
Selenium	3.8*	2.5*	7.0*	5.2*	9.8*
Zinc	1.3	1.1	13	9.1	13

* Estimated values

tendency for bioaccumulation of arsenic in the roots and magnesium in the shoots of water willow. Similar calculations, using data for the contaminated site from Stewart et al. (1992), yielded very similar bioaccumulation values for cadmium, manganese, mercury, nickel and zinc. Their values for chromium and copper were considerably lower. In general, it can be concluded that water willow does not appear to be particularly effective for the bioaccumulation of elements from Kiamichi River sediments.

Mussels

Aluminum, arsenic, cadmium, chromium, copper, iron, magnesium, manganese, mercury, selenium and zinc were detected in all mussel samples (Table 7). Lead was found above its detection limit (3.0 ppm) in only about one-third (36%) of the samples, while nickel was detected in nearly three-fourths (71%) of the samples. The lower limit of detection reported for nickel in mussel tissue was quite variable and the cause is unknown. Nickel concentrations often varied by more than an order of magnitude in replicate samples of the same species from a given location.

Intraspecific variation in the concentration of each element was relatively low when considered in relation to soil, sediment and plant tissue (Table 7). Similar trends in element variability were noted in all three species. Iron and mercury were most variable, while arsenic and copper both exhibited little variability. An attempt to lessen variability by correlating average weight and elemental concentration in the three species yielded no significant relationships.

There were interspecific differences in the concentrations of some elements (Table 7). For example, three-ridge were higher in arsenic and chromium than the other two species, while pistolgrip was highest in copper, and pimpleback was highest in zinc. Selenium was significantly different in all three species. These differences appear to be valid, and not attributable to contamination by sediment in the gut (see Robinson et al. 1993), since concentrations of aluminum were not significantly different among the three species. There were no apparent trends to indicate that one species was consistently higher or lower in all elements.

Metcalfe-Smith (1994) found significant differences in the concentration of chromium, nickel, iron, mercury, aluminum, zinc, copper, manganese and arsenic in two species of mussels collected from the same locations in the St. Lawrence River. No significant differences were detected for cadmium, lead or selenium. Neither species was consistently higher, and additional variation with respect to some elements was noted between males and females of the same species. Overall, the range in concentrations of aluminum, arsenic, cadmium, chromium, copper, iron, selenium, and zinc in the two species from the St. Lawrence River bracketed concentrations in the three species from the Kiamichi River. Manganese and mercury however, were notably higher in the Kiamichi.

Adornato and Martin (1995) reported element concentrations in five species of mussels collected from a single location in the Arkansas River in Tulsa, Oklahoma. Concentrations of iron,

Table 7. Concentrations (ppm) of selected elements in threeridge *(Ambfemuplicutu)*, pimpleback (*Quadrula pustulosa*), and pistolgrip (*Tritgonia verrucosa*) collected from the Kiamichi River in 1994. Means with different letter designations are significantly different at $p \leq 0.05$.

Element	Three-ridge (n = 2 1)		Pimpleback (n = 12)		Pistolgrip (n = 12)	
	Mean	C.V.	Mean	C.V.	Mean	C.V.
Aluminum	474 A	28%	407 A	25%	469 A	29%
Arsenic	4.1 B	15%	3.3 A	11%	3.6 A	10%
Cadmium	2.3 B	18%	3.0 A	19%	2.5 A,B	25%
Chromium	8.6 B	32%	6.3 A	35%	6.0 A	34%
Copper	7.5 A	22%	7.9 A	8.8%	15 B	8.8%
Iron	6095 A,B	43%	8226 A	48%	4804 B	49%
Lead	---	---	---	---	---	---
Magnesium	1287 A	19%	1157 A	17%	1176 A	21%
Manganese	10481 B	32%	7820 A	28%	8412 A,B	21%
Mercury	0.68 A	41%	0.80 A	57%	0.97 A	56%
Nickel	---	---	---	---	---	---
Selenium	2.8 C	30%	2.1 A	31%	3.9 B	18%
zinc	233 B	22%	163 A	23%	237 B	17%
Moisture (%)	83 B	1.1%	81 A	1.6%	82 B	1.8%
Avg. Wt. (g)	3.7 B	46%	2.1 A	29%	3.4 A,B	33%

manganese and mercury were slightly higher in mussels from the Kiamichi. Average concentrations of aluminum, arsenic, cadmium, chromium, copper, nickel, lead, selenium and zinc in the five species from the Arkansas River bracketed the means for the three species in the Kiamichi. Again, the variation found among species makes strict comparisons between locations difficult, but no marked differences in elemental concentrations are apparent.

There are no elemental guidelines or criteria, specifically for the protection of mussels or mussel-eating predators, such as those previously mentioned for sediment. Some elements are essential for biochemical reactions in mussels, and are thus always present in trace amounts. Others are non-essential, but are also invariably present. Interspecific differences, such as those just mentioned, complicate efforts to standardize or compare elemental concentrations from different locations. Most of the elemental concentrations in mussels from this study probably represent background and are not indicative of contaminant problems.

Two elements however, deserve additional comment. Manganese appears to be uniformly high in all three species of mussels. The significance of this phenomenon is unclear, since manganese is not considered highly toxic, but perhaps the source and potential effects of manganese bear additional investigation. Selenium also appears to be high, particularly in light of the fact that Lemly (1993) suggested that 3 ppm be considered the toxic effects threshold for food-chain organisms. Over 90% of the pistolgrip samples exceeded this concentration, along with varying proportions of the other two species (33% and 17% for threeridge and pimpleback, respectively). Mean concentrations of selenium in the five species of mussels from the Arkansas River in Tulsa ranged from 2.4 to 5.2 ppm (Adornato and Martin 1995), while in the St. Lawrence River, the range in two species was 2.0 to 5.2 ppm (Metcalfe-Smith 1994). It is possible that mussels have a slightly higher affinity for accumulation of selenium than other aquatic food-chain organisms.

Mussels are benthic organisms that filter large quantities of water in order to remove and digest suspended particulate matter. Overall, bioaccumulation factors in mussels were higher than those found in plants (Table 6). Less than one-fourth (23%) were equal to or less than 1.0. This included aluminum and iron in all three species, chromium in two, and lead in one species. The majority (64%) of bioaccumulation factors were between 1.0 and 10, with only a few (13%) greater than 10. There was a marked tendency for all three species to bioaccumulate manganese, and two of the three exhibited an affinity for zinc. Bioaccumulation factors for selenium may be higher than those shown, since reliable sediment values were lacking.

CONCLUSIONS AND RECOMMENDATIONS

Bulk element concentrations in soil collected from upland, undisturbed, forested sites throughout the Kiamichi River watershed above Hugo Reservoir were significantly higher than sediment in seven elements (aluminum, arsenic, chromium, iron, lead, manganese and zinc) and no different in three others (copper, magnesium and nickel). Three elements (cadmium, selenium and mercury) could not be compared due to their lack of detection in a sufficient number of samples. Geochemical normalization of soil and sediment data (i.e. the ratio of each element to aluminum) markedly reduced overall variation, and was subsequently used to compare soil and sediment. Four elements (copper, magnesium, manganese and nickel) were apparently enriched in relation to aluminum in sediment, whereas two elements (arsenic and lead) were selectively depleted. There was no difference with respect to chromium iron or zinc. A comparison of bulk element concentrations in the Kiamichi River sediment with guidelines suggested for the protection of benthic organisms indicated that sediments in this section of the river are not likely to be deleterious to benthic animals.

Significant differences in the concentration of arsenic, cadmium, chromium, iron, lead, magnesium and zinc were found between shoots and roots of water willow; whereas concentrations of aluminum, copper, manganese and nickel were similar in the two types of tissue. Mercury and selenium were not detected in plant tissues. Water willow did not bioaccumulate elements from sediments.

Measurable concentrations of eleven elements (aluminum, arsenic, cadmium, chromium, copper, iron, magnesium, manganese, mercury, selenium and zinc) were found in all three species of mussels. In general, intraspecific variation for each element was low compared to soil, sediment and water willow tissues. Interspecific differences were found for all elements except aluminum, magnesium and mercury. In general, bioaccumulation was greater in mussels than in plants. Element concentrations in mussels from the Kiamichi River were comparable to those from non-contaminated areas.

Results of this study can be used as a basis for determining long-term changes in element concentrations in the Kiamichi river ecosystem. A base monitoring program using the mussel *Amblema plicata* is recommended.een recognized as useful monitoring tools because they are long-lived, relatively sedentary, easily sampled, tolerant of many contaminants, have relatively high bioaccumulation factors, and provide a measure of contaminant bioavailability near the entry level of the aquatic food chain (Goldberg 1986). Threeridge was chosen in this case because it is probably the most abundant and most widely distributed mussel in the Kiamichi River. Three replicate, composite samples, consisting of same-size individuals, would be collected at ten-year intervals, from each of the seven general locations used in this study. These locations are near the towns of: (1) Muse, (2) Whitesboro, (3) Tuskahoma, (4) Clayton, (5) Stanley, (6) Eubanks and (7) Antlers. The resulting 21 samples could be analyzed by the same methods employed in this study, at a total cost of approximately $4,000. In the event that significant increases in any element were noted in mussel tissue, resource managers could undertake appropriate, more specific measures to determine the location, cause and possible effects of these changes.

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