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BIOACCUMULATION OF HEAVY METALS IN FISH LIVING IN STORMWATER TREATMENT PONDS

by

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St. Johns River Water Management District
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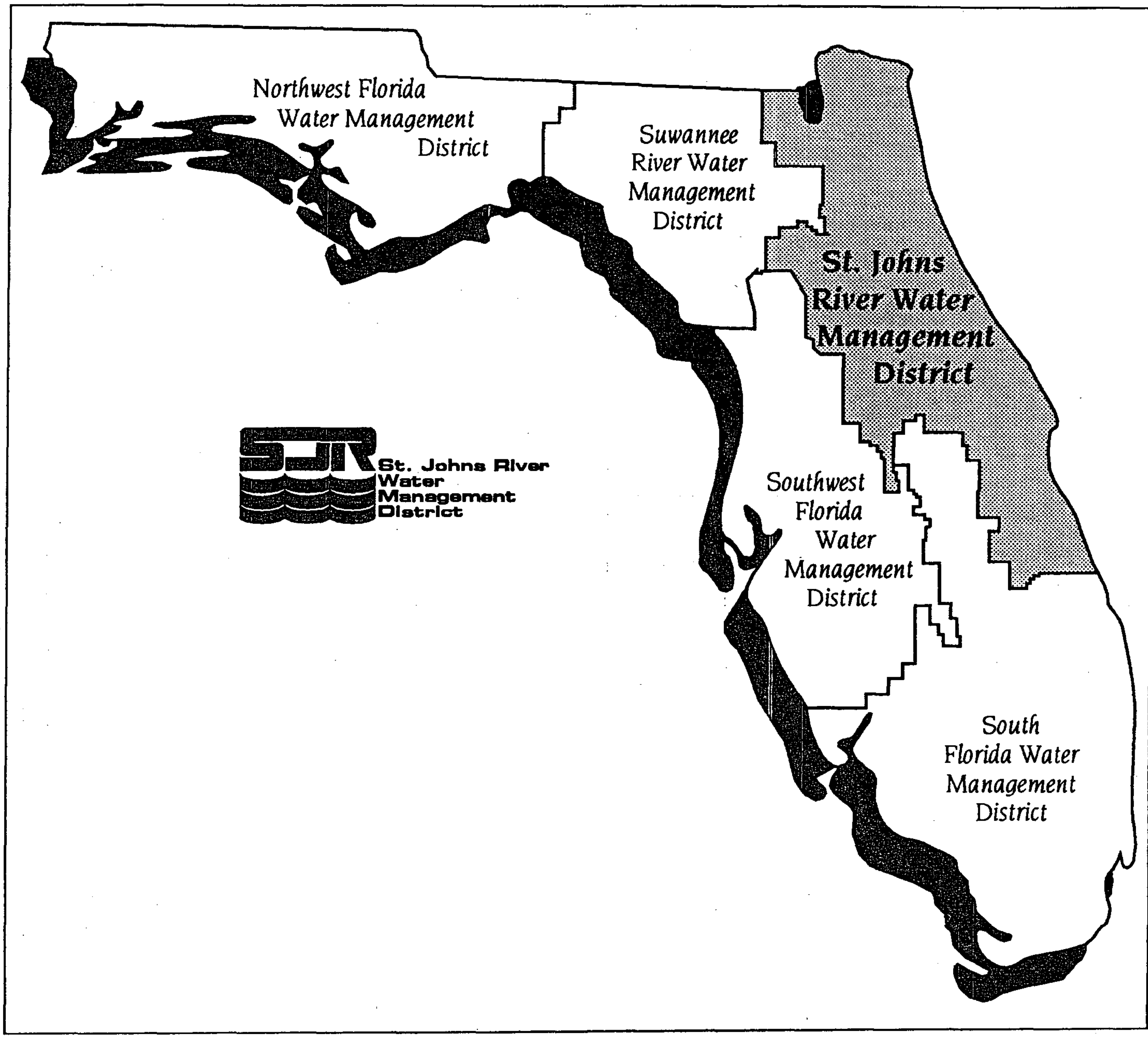

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EXECUTIVE SUMMARY

As land is developed in Florida, a stormwater treatment system, which frequently includes ponds, must be constructed. These ponds, which collect and treat runoff, may be landscaped with selected plants to create habitat for fish and wildlife in compensation for the loss of wetland habitat elsewhere. Studies have shown that urban runoff entering stormwater ponds contains a significant amount of heavy metals, and that the heavy metals concentrate in the sediments. Because the fish that inhabit the stormwater ponds serve as a food source to wading birds and other wildlife, concern has been expressed that the heavy metals may be transferred up through the food chain. This study was conducted to determine whether fish that live in stormwater treatment ponds accumulate significant concentrations of heavy metals and whether fish that forage in different manners bioaccumulate heavy metals in different concentrations.

In 1991, sediment samples and three types of fish were collected from seven stormwater ponds and four natural lakes (control sites) in the greater Orlando area. The sediment samples and fish tissue were analyzed for arsenic (As), chromium (Cr), silver (Ag), cadmium (Cd), nickel (Ni), copper (Cu), lead (Pb), and zinc (Zn) content. The stormwater ponds were constructed 3–5 years ago to serve intensive land uses, such as shopping centers, apartment complexes, or roads.

The study results indicate that Ag, Cd, Ni, Cu, Pb, and Zn are bioaccumulating in certain species of fish living in stormwater ponds. Redear sunfish are bottom feeders that literally dive into the sediment in search of food. The redear sunfish collected from stormwater ponds contained significantly higher concentrations of Ag, Cd, Ni, Cu, Pb, and Zn than those collected from control sites. Largemouth bass, a predator that occupies a high position on the food chain, contained significantly higher concentrations of Cd and Zn in stormwater ponds compared to control sites. Largemouth bass found in stormwater ponds exhibited Ag, Ni, and Pb levels that cause biological concern. The omnivorous

bluegill sunfish, collected from stormwater ponds, contained significantly higher concentrations of Cu.

No significant correlation was observed between metal concentration and the length and weight of any of the three fish species. The differences in heavy metal concentrations between species are related to different foraging strategies, because those fish most strongly associated with sediments exhibited the highest levels of heavy metals.

The data suggest that As and Cr are not bioaccumulating in the fish living in stormwater ponds. The results do suggest, however, that As, Cr, and Pb are bioaccumulating in the fish collected from control ponds in central Florida, with unknown causes and consequences.

The effect on wading birds and other wildlife that feed on the fish living in stormwater ponds is unknown and was beyond the scope of this study. To determine whether stormwater ponds represent a potentially contaminated food source, research is needed to document

- how often predators forage in stormwater ponds,
- the heavy metal concentrations in other faunal components of stormwater ponds (insects, crustaceans, frogs, turtles, etc.), and
- the effects on predators whose food source contains significant heavy metal concentrations.

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INTRODUCTION

Nonpoint sources, such as stormwater runoff, are responsible for the majority of the pollution entering Florida's surface and ground waters. Stormwater runoff has been recognized as a cause of water quality degradation and is responsible for 80–95 percent of the heavy metals that enter Florida surface waters (Livingston and Cox 1985). To address concerns regarding nonpoint source runoff, the St. Johns River Water Management District (District) implemented a stormwater rule (Chapter 40C-42, *Florida Administrative Code*) in 1986. In order to develop land, construction of a stormwater pond or an alternative treatment system is required.

Stormwater ponds provide a benefit to water quality by removing heavy metals and nutrients from the water before it leaves the project area. The District requires that many detention ponds be vegetated for the biological treatment of stormwater. Also, the District commonly approves plans that create habitat for fish and wildlife. These habitats are created by planting desirable aquatic vegetation in the littoral zones of stormwater ponds to compensate for the loss of wetland habitat as a result of land development. This trade-off is known as mitigation.

Wilbur and Hunter (1979) and Owe et al. (1982) have shown that very large quantities of heavy metals are found in urban runoff. Heavy metals found in urban runoff are 10–10,000 times the concentration of heavy metals found in sanitary sewage (Wanielista 1978). Among the toxic heavy metals detected in stormwater runoff, lead, zinc, and copper appear to be the most abundant and detected most frequently (Nightingale 1975, 1987; Whipple and Hunter 1977; EPA 1983). Cadmium, although not present in high concentrations in all urban environments, is significant because of its extreme toxicity (Wigington et al. 1983).

Heavy metal sources are largely associated with the operation of motor vehicles, atmospheric fallout, and road surface materials (Harper 1985). Some sources of heavy metals are displayed in

Table 1. Metal contamination is more widespread from commercial and roadway development than from residential, light industrial, or mixed urban land use (Whalen and Cullum 1988). Harper (1985) determined that the concentrations of heavy metals measured in highway runoff at his Interstate-4/ Maitland Boulevard (Orange County, Florida) study site were substantially lower than those measured by other researchers from northern urban highways with comparable average daily

Table 1. Sources of heavy metals found in stormwater runoff

Source	Cd	Cr	Cu	Ni	Pb	Zn
Gasoline	X		X		X	X
Exhaust emissions				X	X	
Motor oil and grease	X		X	X	X	X
Antifreeze			X			X
Undercoating					X	X
Brake linings		X	X	X	X	X
Rubber	X		X		X	X
Asphalt			X	X		X
Concrete			X		X	X
Diesel oil	X					
Engine wear		X	X			

Note: Cd = cadmium
Cr = chromium
Cu = copper
Ni = nickel
Pb = lead
Zn = zinc

Sources: Wigington et al. 1983; Harper 1985, 1990; Whalen and Cullum 1988 traffic. Harper's (1985) levels were similar to those of a rural Harrisburg, Pennsylvania, highway location. Harper suggested that the differences were linked to the higher rainfall at the Maitland site (rainfall keeps road surfaces relatively clean), the increased industrial activities and particulate emissions associated with northern sites, and the use of salt to deice roadways in the northern locations during the winter months.

Several investigations have been conducted to determine the fate of pollutants within stormwater treatment pond systems (Nightingale 1975, 1987; Wigington et al. 1983; Hvitved-Jacobsen et al. 1984; Harper 1985; Yousef et al. 1985; Hampson 1986). Most of these studies have focused on the ability of bottom sediments to perform as "pollutant sinks." The results of these studies suggest that heavy metals concentrate in the sediment of stormwater ponds. As these ponds receive continual inputs of stormwater that contain heavy metals, processes such as precipitation, coagulation, settling, and biological uptake will result in a large percentage of the input mass being deposited into the sediments (Harper 1985). Nightingale (1975) determined that lead, zinc, and copper accumulated in large amounts (much greater than background levels) in the first few centimeters of the hydrosoil (0–5 centimeters) in an urban runoff retention basin. Arsenic, nickel, copper, and lead were found to accumulate in the first few centimeters of sediment of an urban runoff retention basin (Nightingale 1987). Wigington et al. (1983) investigated the buildup of lead, zinc, cadmium, and copper in selected detention basins in the Washington, D.C., area. They found that these elements were accumulating in the surface soils with little significant downward movement over a period of 6 to 7 years. The results of the research established that arsenic, nickel, copper, and lead do accumulate in the top few centimeters of hydrosoil in basins used for the retention of urban stormwater runoff. Wet-detention stormwater ponds will eventually accumulate bottom sediments rich in trace metals such as lead, zinc, copper, nickel, cadmium, and chromium (Wanielista et al. 1980; Yousef et al. 1991). Most metals (particularly lead, zinc, and copper) are concentrated in the top, loose sediments in significantly high amounts (Yousef et al. 1991). Bottom sediments exhibited a large capacity to retain metals, and the transport of metals through these sediments is a very slow process. It may take more than 20 years to saturate the top 15–20 centimeters of sediments with lead, zinc, and copper (Yousef et al. 1991). Sediments represent the most concentrated physical pool of metals in aquatic environments, and they are ingested by many types of aquatic organisms (Luoma 1983).

Aquatic animals can assimilate metals by ingestion of food, by ion exchange, and through adsorption on tissue and membrane surfaces (Phillips and Russo 1978). Most fish are capable of accumulating most metals from their diet via the gastrointestinal system and from water via various membrane surfaces, particularly the gills. Seelye et al. (1982) have shown that sediments contain toxins that may accumulate in fish indirectly through the food web or directly from exposure to resuspended sediments. Fish exposed to high levels of trace metals in the water can take up substantial quantities of these metals (Atchison et al. 1977). Patrick and Loutit (1978) found that a metal-contaminated diet is a significant source of increased metal levels in fish. Williford et al. (1987) showed that the accumulation of contaminants by fish from sediments was not limited to a food chain transfer mechanism. The tissue concentrations of most metals appear to be more greatly influenced by association with bottom sediments than by the position in the food chain (Wren et al. 1983).

The present study was designed to determine whether the fish that live in stormwater treatment ponds in the Orlando, Florida, area bioaccumulate significant concentrations of arsenic, chromium, silver, cadmium, nickel, copper, lead, and zinc and whether fish with different foraging strategies bioaccumulate heavy metals in different concentrations. Three species of the sunfish family (Centrarchidae) with substantially different foraging strategies were selected for this study: redear sunfish, *Lepomis microlophus;* largemouth bass, *Micropterus salmoides;* and bluegill sunfish, *Lepomis macrochirus.* In this study, bioaccumulation refers to the uptake of metals by these fish from their diet and through their gills. The various species of fish that inhabit stormwater ponds serve as a food source to wildlife, especially wading birds.

Redear sunfish depend largely on mollusks for food and do not compete severely with insect-eating fish. This species has highly developed grinding teeth or "shellcrackers" located in its pharynx which are capable of crushing snails (McClane 1978). In Florida, redear sunfish eat midge larvae, snails, scuds, prawns, and mayfly and dragonfly naiads (Wilbur 1969). Upon finding a snail on the bottom, the redear sunfish assumes a vertical position and literally dives into the sediment, head first (Wilbur 1969).

Largemouth bass are predators that occupy a high position in the food chain. The food of young largemouth bass consists of tiny crustaceans. Larger bass eat insects, crayfish, frogs, and fishes (McClane 1978). In Florida, Cladocera are the major food of bass 13–30 millimeters (mm) in size; amphipods, insects, and decapods are the major food of bass 31–75 mm in size; and fish and decapods are the major food of bass 72–296 mm in size (Carlander 1969; Chew 1974). Bass in ponds without other fish rely on crayfish, frogs, large insects, and young bass as food (Carlander 1969).

The food of bluegill sunfish consists of insects and some vegetation (McClane 1978). Young bluegill sunfish feed on smaller crustaceans and aquatic insects (Carlander 1969). As they grow, bluegill sunfish feed on the larger forms of insects and crustaceans (McClane 1978). The greater consumption of free-swimming organisms indicates that bluegill sunfish are not as oriented to bottom feeding as are the redear sunfish (Wilbur 1969).

METHODS AND MATERIALS

During August, September, and October 1991, stormwater ponds and control sites were selected for preliminary sampling. Stormwater ponds were selected by looking through computer printouts of development projects permitted by the District between 1983 and 1988 and by inspecting portions of the Orlando area that have a high ground-water table, conducive for wet stormwater pond designs. Many of the potential control sites and stormwater ponds were selected during monthly aerial surveillance flights.

Stormwater ponds selected for preliminary sampling had to meet the following criteria:

- The stormwater pond must be of a wet design (wet-detention or detention with filtration) and always contain enough water to support a fish population.

- The development project associated with the stormwater pond must be located in the Orlando area.

- The project must be a commercial development (e.g., a shopping center), a high-density residential development (e.g., an apartment complex), or a road.

- The project must have been built between 1983 and 1988. By 1983, rules had been implemented that required that stormwater management systems be designed and constructed for most projects. These systems had to meet certain rule criteria, and permits from the District or the Florida Department of Environmental Protection were required. If the project was built before the early 1980s, it usually did not have a stormwater management system.

- The stormwater pond could be seined. The pond also must be accessible and not overgrown with vegetation.

- Wading birds must have been observed feeding in the pond.
- Permission to use the stormwater pond as a possible study site must be obtained from the owner of the project (if necessary).

Control sites selected for preliminary sampling had to meet the following criteria:

- The pond or lake did not receive any urban or road runoff.
- The pond or lake must be located in the Orlando area.
- The pond or lake must be accessible, and permission to access it must be obtained from the land owner.

During November 1991, 15 stormwater ponds were selected for preliminary sampling to determine the composition of the fish populations (Table 2). The preliminary sampling (and later collecting) was done during the late fall and early winter of 1991 because the rainy season had ended. At the end of the rainy season, the water levels in the stormwater ponds began to drop, making it easier to catch fish. Sampling was done using a 6-foot (ft) deep by 55-ft long seine with a ⅜-inch (in.) mesh and using a 4-ft deep by 55-ft long seine with a ¼-in. mesh. A johnboat was used when it was necessary to transport the seines across the ponds and to pull in the seines. Each pond was seined at least three times and in different locations to obtain an idea of the fish species composition. One or both seines were used, depending on the depth of the pond and the amount of vegetation in the pond. If the pond contained a lot of algae, pulling the 6-ft seine would be almost impossible. A rope was tied to each end of the seine (because all of the ponds were wider than 50 ft) and then the seine was pulled along the length of the pond. Using this technique, the seine was pulled through the middle of each pond.

Of the 15 stormwater ponds sampled, 7 were selected for further study (Figure 1 and Table 3). Of the ponds selected, three served shopping centers, two served apartment complexes, and

Table 2. Stormwater ponds selected for preliminary sampling, November 1991, Orlando, Florida

Project Name	Land Use	Species of Fish Collected During Sampling
Apopka Wal-Mart	Shopping center	None
Briar Creek Apartments	Apartment complex	Redear sunfish, *Lepomis microlophus* Bluegill sunfish, *Lepomis macrochirus* Warmouth bass, *Lepomis gulosus* Mosquitofish, *Gambusia holbrooki*
Country Lake Village	Shopping center	Redear sunfish, *Lepomis microlophus* Redbreast sunfish, *Lepomis auritus*
Jamestown Plaza	Shopping center	Mosquitofish, *Gambusia holbrooki* Sailfin molly, *Poecilia latipinna* Warmouth bass, *Lepomis gulosus* Redear sunfish, *Lepomis microlophus*
Lake Way	Road	Largemouth bass, *Micropterus salmoides* Bluegill sunfish, *Lepomis macrochirus*
Lake Howell Square	Shopping center	Largemouth bass, *Micropterus salmoides* Bluegill sunfish, *Lepomis macrochirus* Grass carp hybrid, *Hypothalmichthys nobilis x Ctenopharyngodon idella*
Lake Fredrica Center	Shopping center	Mosquitofish, *Gambusia holbrooki*
Longwood Business Center	Commercial center	Mosquitofish, *Gambusia holbrooki*
Piedmont Plaza	Shopping center	Bluegill sunfish, *Lepomis macrochirus* Golden shiner, *Notemigonus crysoleucas* Mosquitofish, *Gambusia holbrooki*
Regatta Shores	Apartment complex	Bluegill sunfish, *Lepomis macrochirus* Sailfin molly, *Poecilia latipinna* Mosquitofish, *Gambusia holbrooki*
Southbrooke	Apartment complex	Bluegill sunfish, *Lepomis macrochirus* Redear sunfish, *Lepomis microlophus* Redbreast sunfish, *Lepomis auritus* Mosquitofish, *Gambusia holbrooki* Least killifish, *Heterandria formosa*
The Park	Apartment complex	Mosquitofish, *Gambusia holbrooki*

Table 2—*Continued*

Project Name	Land Use	Species of Fish Collected During Sampling
Timberlake	Apartment complex	Mosquitofish, *Gambusia holbrooki*
University Boulevard	Road	Largemouth bass, *Micropterus salmoides* Bluegill sunfish, *Lepomis macrochirus* Warmouth bass, *Lepomis gulosus* Mosquitofish, *Gambusia holbrooki*
Willa Springs Village	Shopping center	Mosquitofish, *Gambusia holbrooki*

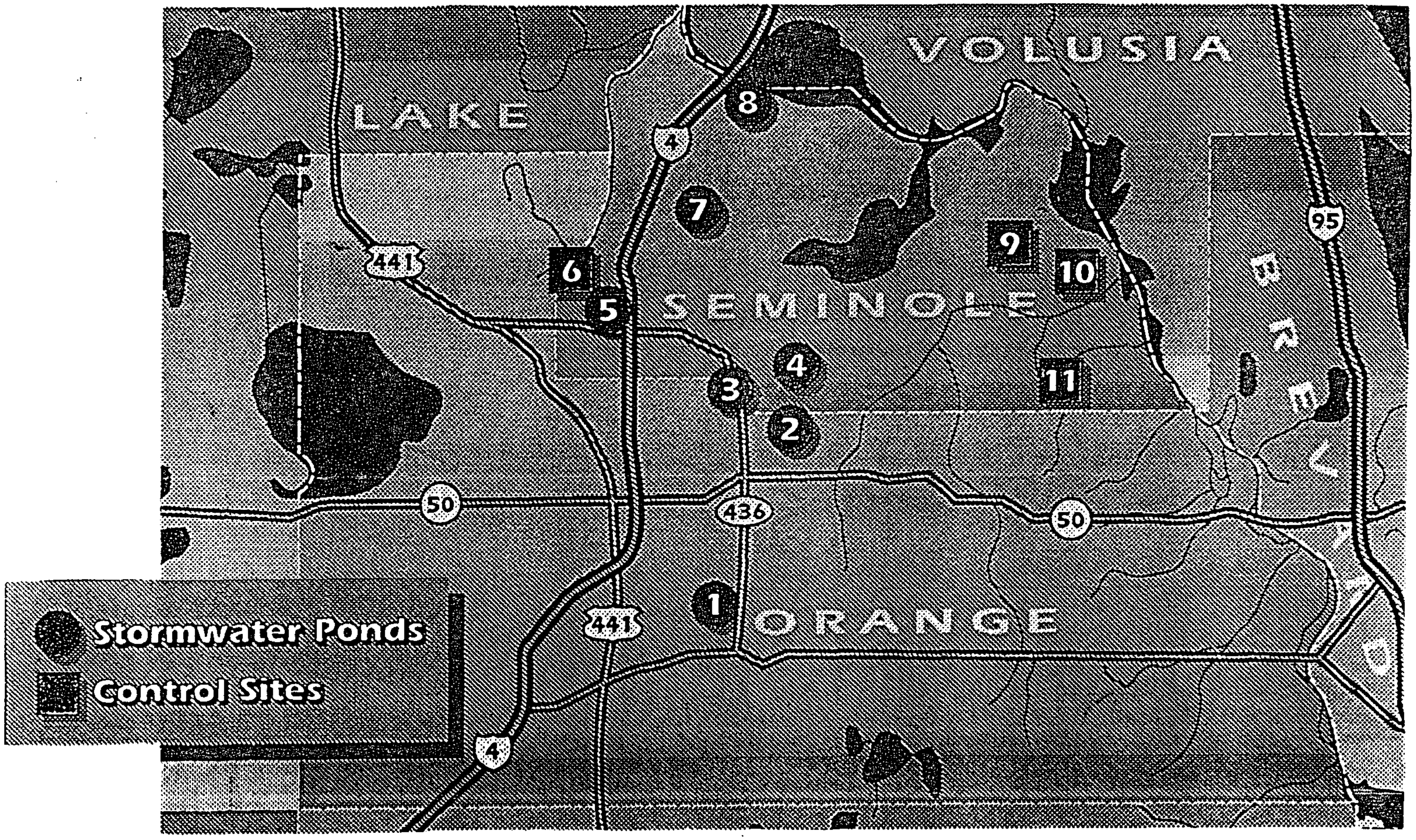

Figure 1. Location of stormwater ponds and control sites where fish were collected for heavy metal analysis, December 1991–March 1992, Orlando, Florida. *Sites are described in Table 4.*

Table 3. Stormwater ponds selected for fish collection, December 1991 and January 1992, Orlando, Florida

Project Name	Land Use	Year Built	Type of Pond	Species of Fish Collected
Briar Creek Apartments	Apartment complex	1987	Wet-detention	Redear sunfish
Country Lake Village	Shopping center	1988	Wet-detention with filtration	Redear sunfish
Jamestown Plaza	Shopping center	1986	Wet-detention with filtration	Redear sunfish
Lake Howell Square	Shopping center	1986	Wet-detention with filtration	Largemouth bass Bluegill sunfish
Lake Way	Road	1986	Wet-detention with filtration	Largemouth bass
Regatta Shores	Apartment complex	1988	Wet-detention with filtration	Bluegill sunfish
University Boulevard	Road	1986	Wet-detention	Largemouth bass Bluegill sunfish

two served road projects. Two of the stormwater ponds contained largemouth bass and bluegill sunfish. One of the ponds contained bluegill sunfish, and one contained largemouth bass. Three stormwater ponds contained redear sunfish.

Four control sites were selected for the study in December 1991 (Figure 1 and Table 4). Because the species of fish selected for collection are species common to most central Florida lakes and ponds and because collecting fish from the control sites by seining is difficult, preliminary sampling was not done in most of the control sites.

During December 1991 and January 1992, fish were collected from the seven stormwater ponds. Fish were collected using the two sizes of seines specified earlier and in accordance with techniques already described. In addition, a 6-ft deep by 150-ft long gill net with a 1½-in. mesh was used to collect some of the largemouth bass. The gill net was

Table 4. Description of sampling sites, Orlando, Florida, December 1991–March 1992

Number*	Type	Site	Description
1	Stormwater pond	Briar Creek Apartments	Apartment complex, built in 1987
2	Stormwater pond	University Boulevard	Road, built in 1986
3	Stormwater pond	Lake Howell Square	Shopping center, built in 1986
4	Stormwater pond	Country Lake Village	Shopping center, built in 1988
5	Stormwater pond	Jamestown Plaza	Shopping center, built in 1986
6	Control	Sand Lake	Lake located within Wekiwa Springs State Park
7	Stormwater pond	Lake Way	Road, built in 1986
8	Stormwater pond	Regatta Shores	Apartment complex, built in 1988
9	Control	Buck Lake	Lake located near Geneva
10	Control	E.H. Kilbee Ranch	Pond on large ranch near St. Johns River
11	Control	Unnamed lake	Lake located near Chuluota

* Numbers used on Figure 1

set during seining or left overnight. A small johnboat was used to set the gill net. Five largemouth bass were collected from each of three stormwater ponds containing them; five bluegill sunfish were collected from each of three ponds; and five redear sunfish were collected from each of three ponds. A total of fifteen individuals of each of the three species was collected from the stormwater ponds.

In December 1991 and January and March 1992, fish were collected from the four control sites. Five redear sunfish were collected from a pond (located on the E.H. Kilbee Ranch) using the 6-ft by 55-ft seine net. Largemouth bass, redear sunfish, and bluegill sunfish were collected from three of the control sites with an electrofishing boat. Five individuals of each of the three species of fish were collected from Sand Lake and Buck Lake. Five largemouth bass and five bluegill sunfish were collected from an unnamed lake near Chuluota. A total of fifteen individuals of each of the three species were collected from the control sites.

Upon collection, the standard length and total length of each fish were measured in centimeters. Once a fish was measured, it was tagged with a paper tag bearing a permanent identification number. Each fish was then placed in a sterile plastic bag that was marked in permanent ink with the identification number and date collected. The fish were placed on ice and later frozen until they were taken to the laboratory for analysis.

A composite sediment sample was collected from each of the seven stormwater ponds and four control sites on or near the date that the fish were collected. A sediment sample was collected with an Ekman dredge, from three different locations in each pond. The top 3 in. of each sample, excluding the material touching the interior of the dredge, was combined in a bucket and mixed (while wearing sterile plastic gloves) to obtain a composite sample. Each composite sediment sample was placed in a sterile plastic bag, marked in permanent ink with an identification number, and kept on ice until it was taken to the laboratory for analysis.

The fish (90 individuals total) and the composite sediment samples (11 samples) were taken to Flowers Chemical Laboratories in Altamonte Springs, Florida, for metal analysis. This laboratory is a state-certified laboratory; methods of analysis were in accordance with Environmental Protection Agency (EPA) methodologies. At the laboratory, each fish was weighed to the nearest 0.1 gram (g) on a triple-beam balance.

Each fish was pureed in a Waring blender. A subsample (0.2–0.5 g) of each puree was used in the microwave digestion procedure. Each subsample was digested according to EPA Method 3051 (EPA 1986). Each fish was analyzed for arsenic (As), chromium (Cr), silver (Ag), cadmium (Cd), nickel (Ni), copper (Cu), lead (Pb), and zinc (Zn) using atomic absorption methods, EPA Method 7000 (EPA 1986). Metal detection methods (EPA 1986) and minimum levels of detection were as follows:

- As—Atomic Absorption Gaseous Hydride, EPA Method 7061, 0.0005 milligrams per kilogram of wet weight (mg/kg wet wt)
- Cr—Atomic Absorption Direct Aspiration, EPA Method 7190, 0.002 mg/kg wet wt
- Ag—Atomic Absorption Direct Aspiration, EPA Method 7760, 0.001 mg/kg wet wt
- Cd—Atomic Absorption Direct Aspiration, EPA Method 7130, 0.001 mg/kg wet wt
- Ni—Atomic Absorption Direct Aspiration, EPA Method 7520, 0.001 mg/kg wet wt
- Cu—Atomic Absorption Direct Aspiration, EPA Method 7210, 0.005 mg/kg wet wt
- Pb—Atomic Absorption Furnace Technique, EPA Method 7421, 0.001 mg/kg wet wt
- Zn—Atomic Absorption Direct Aspiration, EPA Method 7950, 0.001 mg/kg wet wt

A representative 0.5 g of each sediment sample was digested using the appropriate EPA method described above. Each sediment sample was analyzed for the same metals by the same methods described above. All metal concentrations were determined on a wet weight basis; unit of measurement used was milligrams per kilogram wet weight.

Statistical Analysis Systems software (SAS Institute 1985) was used on an IBM 4381 mainframe computer to analyze the data. The data were analyzed by using an analysis of variance. The Bonferroni Multiple Comparisons Procedure was used to compare the mean metal concentrations. The level of significance was set at $p<0.005$. Statistical tests were conducted to determine whether the data met the assumptions of normal distribution and equal variances. The Wilkes-Shapiro Test was used to test for normality. The Dixon and Massey Degrees of Freedom Adjustment for Unequal Variances was used to determine whether the equal variance assumption was met (Zar 1984). A correlation analysis of the data was run to determine whether there was a correlation between the length and weight of the fish and the heavy metal concentration; this was done for all three species and all eight metals.

Giesy and Wiener (1977) suggested using caution in the analysis of data on metal concentrations in fish because these concentrations often are highly variable. Consequently, the data often are non-normally distributed, and assumptions for parametric statistics are not met. Many researchers who have examined heavy metals in fish have used nonparametric statistical methods and/or have transformed their data because of the variability. For this reason, the data in the present study were analyzed to determine whether the assumptions of normal distribution and equal variances were met. There was variability in the data; however, the data did not deviate significantly from the assumptions. Thus, the use of parametric methods to analyze the data was acceptable.

The sediment samples collected in the present study were composites; therefore, the variation was masked, and the results could not be directly compared or correlated with those of the fish. Because of the small sample sizes and masked variation, variation in samples collected from stormwater ponds and from control sites was greater than the variation in the collective samples from stormwater ponds and control sites. For this reason, significant differences in the metal concentrations of the composite sediment samples could not be shown.

RESULTS

The mean length of redear sunfish and largemouth bass collected from stormwater ponds and control sites was not significantly different (Table 5). The mean length of the bluegill sunfish collected from stormwater ponds and control sites, however, was significantly different ($p<0.008$).

The mean weight of redear sunfish and largemouth bass collected from stormwater ponds and control sites was not significantly different (Table 6). The mean weight of the bluegill sunfish collected from stormwater ponds and control sites, however, was significantly different ($p<0.008$).

Statistical analysis of the data indicated that the data met the assumptions of normal distribution and equal variances. Results of the Wilkes-Shapiro Test showed that the data did not deviate significantly from normality. The Dixon and Massey Degrees of Freedom Adjustment for Unequal Variances test determined that the variances were equal enough to meet the assumption of equal variances.

ARSENIC

The mean As concentration in redear sunfish was higher in fish collected from the control sites than in those from stormwater ponds (Table 7 and Figure 2 [see end of chapter for Tables 7–14 and Figures 2–17]); the difference was not statistically significant. Largemouth bass collected from the control sites also contained a higher mean As concentration than those from stormwater ponds (Table 8 and Figure 2); the difference also was not statistically significant. Largemouth bass collected from the control sites contained the highest mean As concentration of any fish sampled. The bluegill sunfish collected from stormwater ponds and control sites contained mean As concentrations that were below detectable limits (Table 9 and Figure 2).

Table 5. Mean total length (cm ± SD) of fish collected during study, December 1991–March 1992, Orlando, Florida

Species	Stormwater Ponds (N=15)	Control Sites (N=15)	*p* Value
Redear sunfish, *Lepomis microlophus*	11.50 ± 2.72	12.11 ± 1.92	0.4866
Largemouth bass, *Micropterus salmoides*	14.57 ± 6.59	20.43 ± 6.58	0.0214
Bluegill sunfish, *Lepomis macrochirus*	9.28 ± 2.37	14.60 ± 3.32	0.0000

Table 6. Mean weight (g ± SD) of fish collected during study, December 1991–March 1992, Orlando, Florida

Species	Stormwater Ponds (N=15)	Control Sites (N=15)	*p* Value
Redear sunfish, *Lepomis microlophus*	33.52 ± 29.12	27.83 ± 13.37	0.5003
Largemouth bass, *Micropterus salmoides*	55.57 ± 64.20	116.67 ± 109.37	0.0726
Bluegill sunfish, *Lepomis macrochirus*	14.99 ± 11.28	57.76 ± 41.32	0.0006

Composite sediment samples collected from the control sites had a mean As concentration approximately ten times higher than those from stormwater ponds (Table 10); however, the difference was not statistically significant.

No significant correlation was observed between the mean As concentration and the length and weight of the three species of fish (Tables 11, 12, and 13).

CHROMIUM

The mean Cr concentration in redear sunfish was higher in fish collected from the control sites than in those from stormwater ponds (Table 7 and Figure 3); the difference was not statistically significant. Largemouth bass collected from the control sites also contained a higher mean Cr concentration than those from stormwater ponds (Table 8 and Figure 3); the difference was statistically significant ($p<0.005$). Largemouth bass collected from the control sites contained the highest mean Cr concentration of any fish sampled. The mean Cr concentrations in bluegill sunfish collected from stormwater ponds and control sites were fairly similar and not statistically different (Table 9 and Figure 3).

Composite sediment samples collected from the control sites had a mean Cr concentration approximately two times higher than those from stormwater ponds (Table 10); however, the difference was not statistically significant.

No significant correlation was observed between the mean Cr concentration and the length and weight of the three species of fish (Tables 11, 12, and 13).

SILVER

The mean Ag concentration was higher in the fish collected from stormwater ponds than in those from control sites (Figure 4). The mean Ag concentration in redear sunfish was significantly different ($p<0.005$) (Table 7). Redear sunfish collected from the stormwater ponds contained the highest mean Ag concentration of any fish collected (Figure 4). The differences between mean Ag concentrations of the largemouth bass and bluegill sunfish collected from stormwater ponds and control sites were not significantly different (Tables 8 and 9).

Composite sediment samples collected from the control sites had a higher mean Ag concentration than those from stormwater ponds (Table 10); however, the difference was not statistically significant.

No significant correlation was observed between the mean Ag concentration and the length and weight of the three species of fish (Tables 11, 12, and 13).

CADMIUM

The mean Cd concentrations of two of the three species of fish were significantly different ($p<0.005$). Redear sunfish and largemouth bass collected from stormwater ponds contained mean Cd concentrations that were significantly higher ($p<0.005$) than in those from control sites (Tables 7 and 8 and Figure 5). Largemouth bass collected from stormwater ponds contained the highest mean Cd concentration of any fish sampled. The mean Cd concentration in bluegill sunfish was higher in fish collected from the stormwater ponds than in those from control sites (Table 9); the difference was not significantly different. This concept does not show up well in Figure 5 because the values are so small.

Composite sediment samples collected from stormwater ponds contained a higher mean Cd concentration than those from the control sites (Table 10); however, the difference was not significant.

No significant correlation was observed between the mean Cd concentration and the length and weight of the three species of fish (Tables 11, 12, and 13).

NICKEL

The mean Ni concentration in redear sunfish was significantly higher ($p<0.005$) in fish collected from stormwater ponds than in those from control sites (Table 7 and Figure 6). Redear sunfish collected from the stormwater ponds contained the highest mean Ni concentration of any fish sampled (Figure 6). Largemouth bass and bluegill sunfish collected from stormwater ponds contained higher mean Ni concentrations than those from control sites (Table 8 and Figure 6); however, the differences were not statistically significant.

Composite sediment samples collected from the stormwater ponds had a mean Ni concentration approximately 30 times higher than those from the control sites (Table 10); however, the difference was not statistically significant.

No significant correlation was observed between the mean Ni concentration and the length and weight of the three species of fish (Tables 11, 12, and 13).

COPPER

The mean Cu concentration in redear sunfish was higher in fish collected from stormwater ponds than in those from control sites (Table 7 and Figure 7); the difference was significantly higher ($p<0.005$). Individuals of this species collected from stormwater ponds contained the highest mean Cu concentration. Largemouth bass collected from the control sites had a slightly higher mean Cu concentration than those from stormwater ponds (Table 8 and Figure 7); the difference was not statistically significant. Bluegill sunfish collected from stormwater ponds contained a higher mean Cu concentration than those from the control sites (Table 9 and Figure 7); the difference was statistically significant ($p<0.005$).

Composite sediment samples collected from the stormwater ponds had a mean Cu concentration over four times higher than those from the control sites (Table 10); however, the difference was not statistically significant.

No significant correlation was observed between the mean Cu concentration and the length and weight of the three species of fish (Tables 11, 12, and 13).

LEAD

The mean Pb concentration in redear sunfish was significantly higher ($p<0.005$) in fish collected from stormwater ponds than in those from the control sites (Table 7 and Figure 8). This species collected from stormwater ponds contained the highest mean Pb concentration of any fish sampled. Largemouth bass collected from stormwater ponds contained a higher mean Pb concentration than those from the control sites (Table 8 and Figure 8); the difference was not significant. The mean Pb concentration in bluegill sunfish was higher in fish collected from the stormwater ponds than in those from control sites (Table 9 and Figure 8); the difference was not significantly different. Mean Pb concentrations of the bluegill sunfish were significantly different ($p<0.005$) from those of both the redear sunfish and the largemouth bass.

Composite sediment samples collected from the control sites had a mean Pb concentration approximately two times higher than those from stormwater ponds (Table 10); however, the difference was not statistically significant.

No significant correlation was observed between the mean Pb concentration and the length and weight of the three species of fish (Tables 11, 12, and 13).

ZINC

The mean Zn concentration of redear sunfish and largemouth bass was significantly higher ($p<0.005$) in fish collected from stormwater ponds than in those from the control sites (Tables 7 and 8 and Figure 9). Redear sunfish collected from stormwater ponds contained the highest mean Zn concentrations of any fish sampled. The mean Zn concentration in bluegill sunfish was higher in fish collected from stormwater ponds than in those from control sites (Table 9 and Figure 9); the difference was not significantly different.

Composite sediment samples collected from stormwater ponds had a mean Zn concentration approximately three times higher than those from the control sites (Table 10); however, the difference was not significantly different.

No significant correlation was observed between the mean Zn concentration and the length and weight of the three species of fish (Tables 11, 12, and 13).

SUMMARY OF METAL RESULTS

Redear sunfish collected from stormwater ponds bioaccumulated significantly higher concentrations of Ag, Cd, Ni, Cu, Pb, and Zn than those from the control sites (Table 14 and Figures 10 and 11).

Largemouth bass collected from stormwater ponds bioaccumulated significantly higher concentrations of Cd and Zn than largemouth bass collected from the control sites (Table 14 and Figures 12 and 13). Chromium was bioaccumulated to significantly higher concentrations in the largemouth bass collected from the control sites, compared to those from stormwater ponds.

Bluegill sunfish collected from stormwater ponds bioaccumulated significantly higher concentrations of Cu than those from the control sites (Table 14 and Figures 14 and 15).

No significant differences were observed in metal concentrations between composite sediment samples collected from stormwater ponds and control sites (Table 14 and Figures 16 and 17).

Table 7. Mean ± SD heavy metal concentrations (mg/kg wet weight) of redear sunfish, *Lepomis microlophus*, collected December 1991–March 1992, Orlando, Florida

Heavy Metal	Stormwater Ponds (N=15)	Control Sites (N=15)	*p* Value
Arsenic	0.0116 ± 0.0182	0.0289 ± 0.0793	0.4166
Chromium	0.205 ± 0.559	0.437 ± 0.215	0.1449
Silver	0.458 ± 0.413	0.001*	0.0002
Cadmium	1.64 ± 0.918	0.198 ± 0.150	0.0000
Nickel	5.32 ± 3.65	0.576 ± 0.397	0.0000
Copper	6.37 ± 3.56	0.879 ± 0.388	0.0000
Lead	15.78 ± 6.99	5.27 ± 3.16	0.0000
Zinc	42.42 ± 19.68	24.83 ± 4.52	0.0000

*All values below limits of detection

Table 8. Mean ± SD heavy metal concentrations (mg/kg wet weight) of largemouth bass, *Micropterus salmoides*, collected December 1991–March 1992, Orlando, Florida

Heavy Metal	Stormwater Ponds (N=15)	Control Sites (N=15)	*p* Value
Arsenic	0.00896 ± 0.0125	0.0778 ± 0.158	0.1045
Chromium	0.108 ± 0.299	0.658 ± 0.232	0.0000
Silver	0.419 ± 0.462	0.0418 ± 0.158	0.0057
Cadmium	3.16 ± 1.65	0.241 ± 0.156	0.0000
Nickel	2.46 ± 2.32	1.18 ± 1.09	0.0648
Copper	3.81 ± 2.25	4.71 ± 11.52	0.7677
Lead	12.04 ± 7.77	5.77 ± 3.29	0.0076
Zinc	29.99 ± 8.52	21.18 ± 7.20	0.0048

Table 9. Mean ± SD heavy metal concentrations (mg/kg wet weight) of bluegill sunfish, *Lepomis macrochirus*, collected December 1991–March 1992, Orlando, Florida

Heavy Metal	Stormwater Ponds (N=15)	Control Sites (N=15)	*p* Value
Arsenic	0.008*	0.008*	**
Chromium	0.532 ± 0.124	0.489 ± 0.105	0.3165
Silver	0.0278 ± 0.0763	0.00140 ± 0.00157	0.1905
Cadmium	0.00577 ± 0.0122	0.00358 ± 0.00800	0.5677
Nickel	0.156 ± 0.199	0.0462 ± 0.076	0.0566
Copper	2.08 ± 1.19	1.07 ± 0.327	0.0037
Lead	0.767 ± 0.528	0.537 ± 0.464	0.2153
Zinc	36.61 ± 10.32	30.72 ± 7.49	0.0842

*All values below limits of detection
**Could not be calculated

Table 10. Mean ± SD heavy metal concentrations (mg/kg wet weight) of composite sediment samples collected December 1991–March 1992, Orlando, Florida

Heavy Metal	Stormwater Ponds (N=7)	Control Sites (N=4)	*p* Value
Arsenic	3.06 ± 5.59	31.12 ± 44.19	0.1302
Chromium	2.18 ± 0.843	4.27 ± 5.82	0.3572
Silver	0.177 ± 0.116	0.337 ± 0.233	0.1565
Cadmium	0.280 ± 0.204	0.107 ± 0.041	0.1360
Nickel	2.35 ± 4.05	0.0703 ± 0.0646	0.3013
Copper	14.11 ± 12.02	2.98 ± 2.71	0.1080
Lead	4.91 ± 2.75	10.93 ± 11.77	0.2125
Zinc	28.82 ± 18.47	10.25 ± 3.93	0.0839

Table 11. Correlation coefficients of heavy metal concentrations versus length and weight of redear sunfish, *Lepomis microlophus* collected December 1991–March 1992, Orlando, Florida. *All correlations were nonsignificant at* p>*0.05.*

Heavy Metal	Length	Weight
Arsenic	0.0329	-0.0914
Chromium	0.4683	0.3745
Silver	0.1339	0.0919
Cadmium	-0.6194	-0.4737
Nickel	0.3904	0.2587
Copper	-0.0146	-0.0399
Lead	-0.1844	-0.2221
Zinc	-0.4363	-0.3581

Table 12. Correlation coefficients of heavy metal concentrations versus length and weight of largemouth bass, *Micropterus salmoides*, collected December 1991–March 1992, Orlando, Florida. *All correlations were nonsignificant at* p>*0.05.*

Heavy Metal	Length	Weight
Arsenic	-0.0888	-0.0515
Chromium	-0.2292	-0.2322
Silver	0.1225	0.3657
Cadmium	0.0196	0.1463
Nickel	0.0558	0.2672
Copper	0.0114	0.1690
Lead	0.0689	0.2623
Zinc	0.0056	0.083

Table 13. Correlation coefficients of heavy metal concentrations versus length and weight of bluegill sunfish, *Lepomis macrochirus*, collected December 1991–March 1992, Orlando, Florida. *All correlations were nonsignificant at* p>*0.05.*

Heavy Metal	Length	Weight
Arsenic	0.0000	0.0000
Chromium	-0.3172	-0.3073
Silver	0.0094	-0.0356
Cadmium	0.1890	0.2998
Nickel	-0.3784	-0.3230
Copper	-0.4109	-0.2817
Lead	-0.2050	-0.2345
Zinc	-0.6181	-0.6249

Table 14. Summary of results for fish and sediment samples collected during the study, December 1991–March 1992, Orlando, Florida

Heavy Metal	Redear Sunfish S/C	Largemouth Bass S/C	Bluegill Sunfish S/C	Sediment S/C
Arsenic	-/+	-/+	NA/NA	-/+
Chromium	-/+	-/+*	+/-	-/+
Silver	+/-*	+/-	+/-	-/+
Cadmium	+/-*	+/-*	+/-	+/-
Nickel	+/-*	+/-	+/-	+/-
Copper	+/-*	-/+	+/-*	+/-
Lead	+/-*	+/-	+/-	-/+
Zinc	+/-*	+/-*	+/-	+/-

S/C = from stormwater ponds/from control sites
NA = not applicable
- = lower mean value
+ = higher mean value
*Indicates those datasets significantly different at $p<0.005$

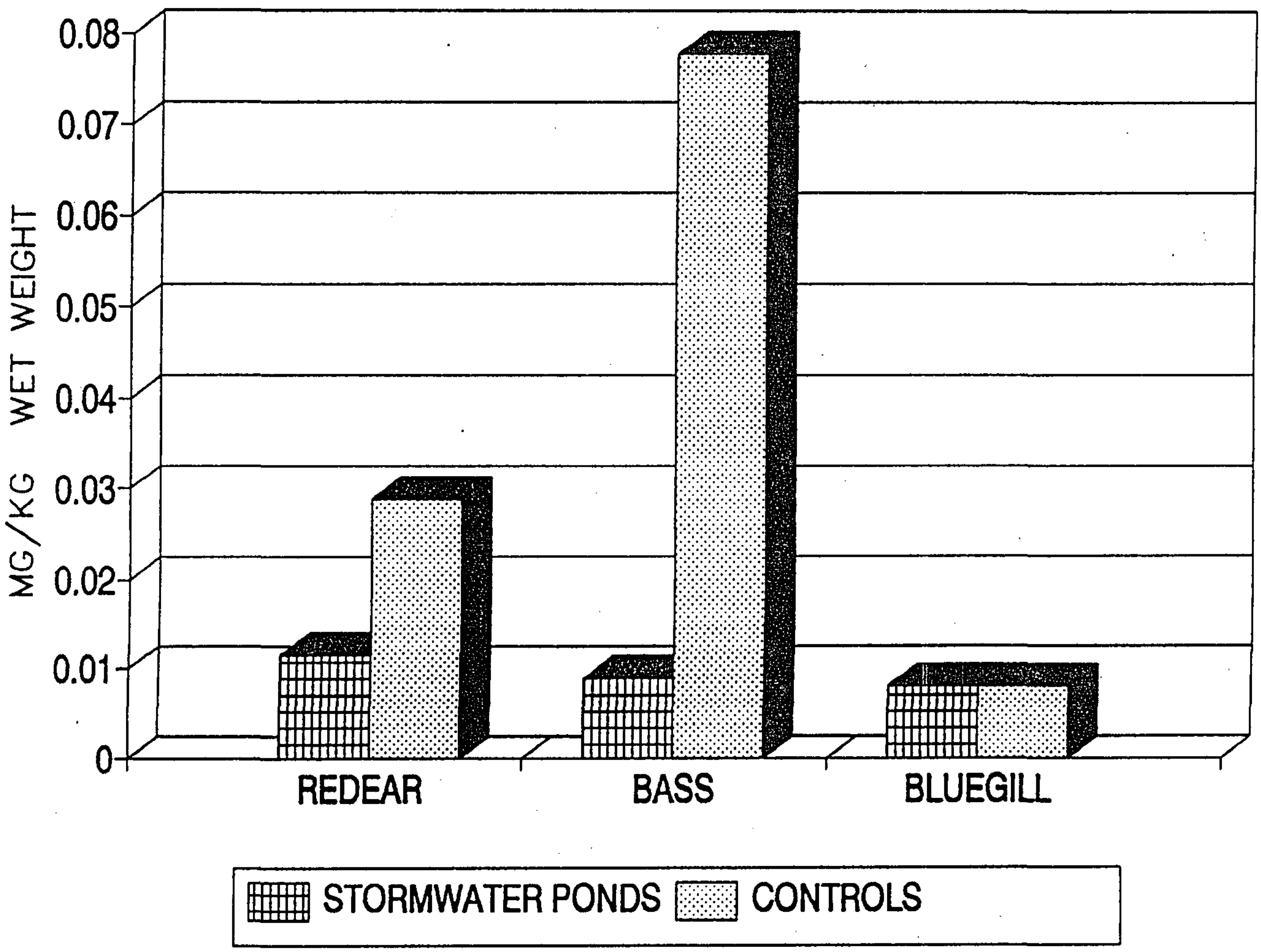

Figure 2. **Mean arsenic concentrations of redear sunfish, *Lepomis microlophus*; largemouth bass, *Micropterus salmoides*; and bluegill sunfish, *Lepomis macrochirus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida**

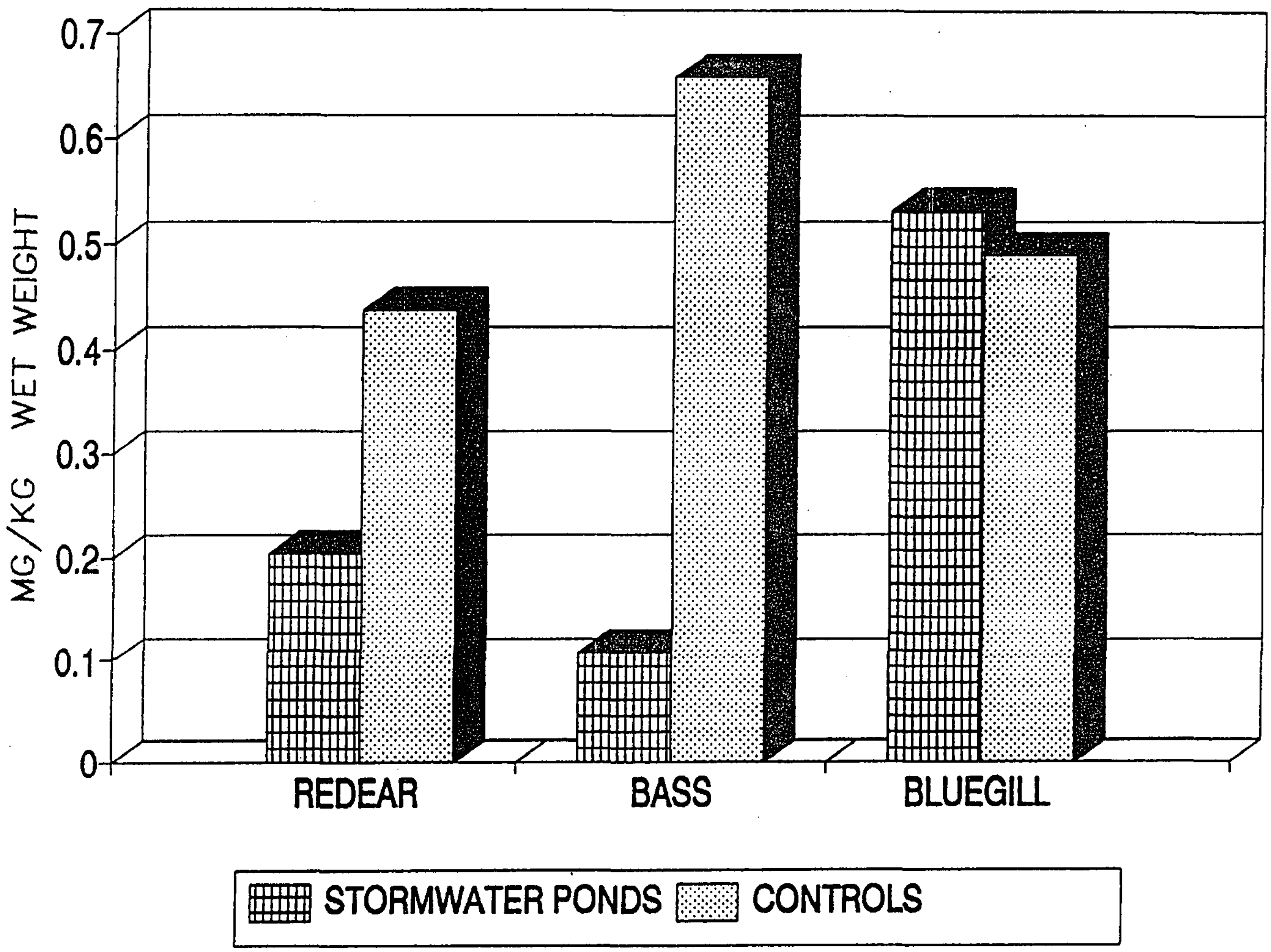

Figure 3. Mean chromium concentrations of redear sunfish, *Lepomis microlophus*; largemouth bass, *Micropterus salmoides*; and bluegill sunfish, *Lepomis macrochirus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida

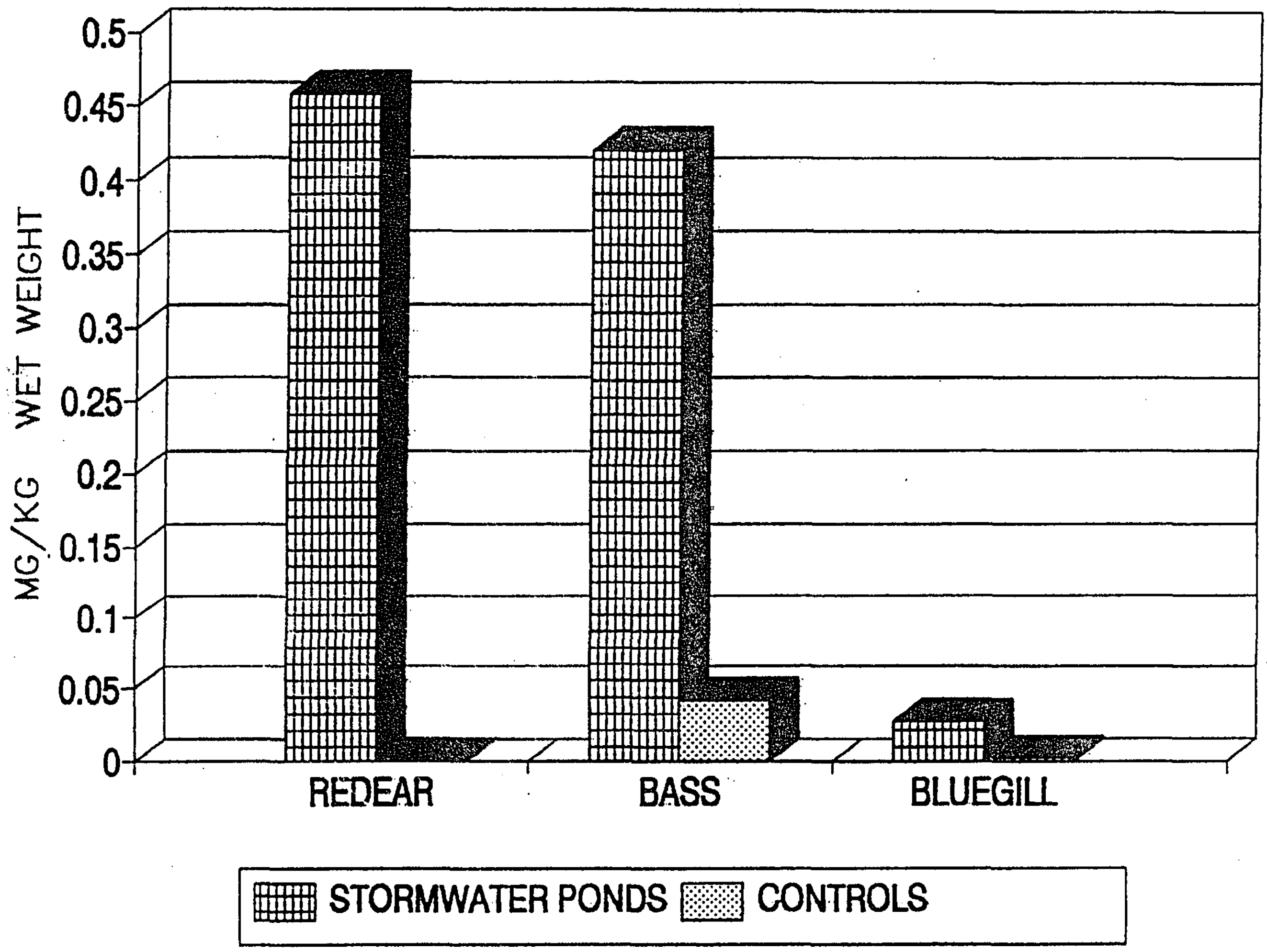

Figure 4. **Mean silver concentrations of redear sunfish, *Lepomis microlophus*; largemouth bass, *Micropterus salmoides*; and bluegill sunfish, *Lepomis macrochirus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida**

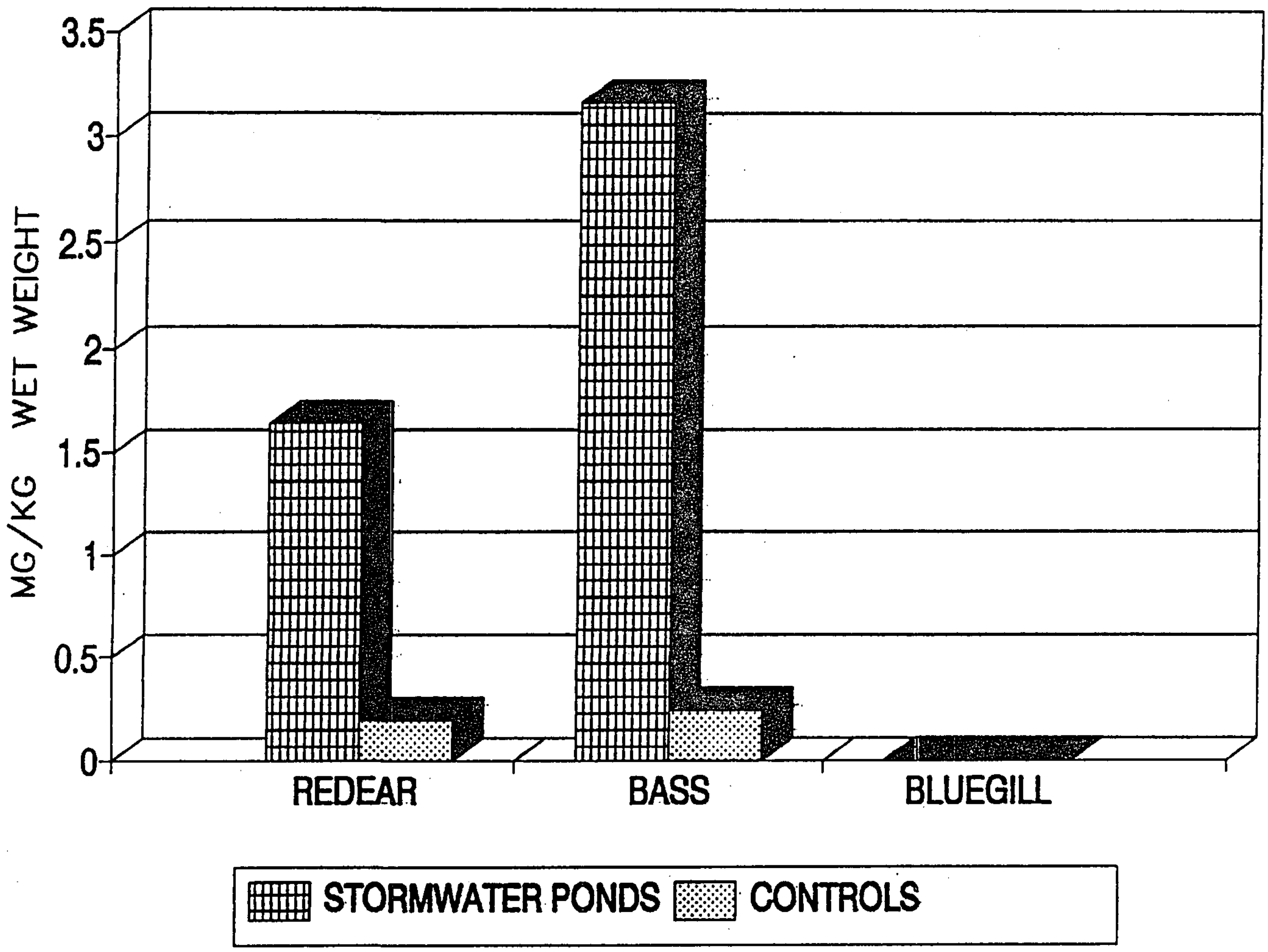

Figure 5. Mean cadmium concentrations of redear sunfish, *Lepomis microlophus*; largemouth bass, *Micropterus salmoides*; and bluegill sunfish, *Lepomis macrochirus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida

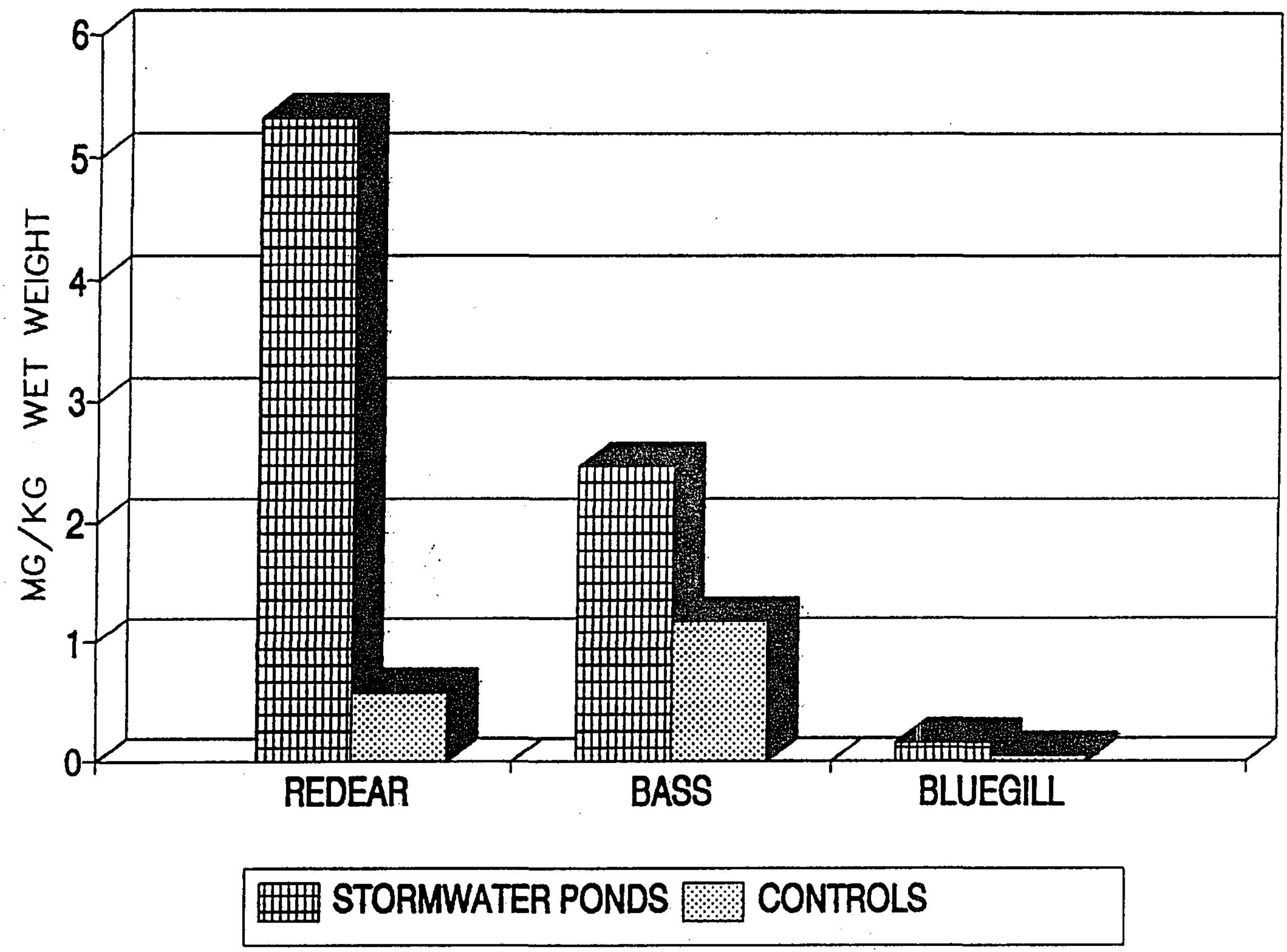

Figure 6. **Mean nickel concentrations of redear sunfish, *Lepomis microlophus*; largemouth bass, *Micropterus salmoides*; and bluegill sunfish, *Lepomis macrochirus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida**

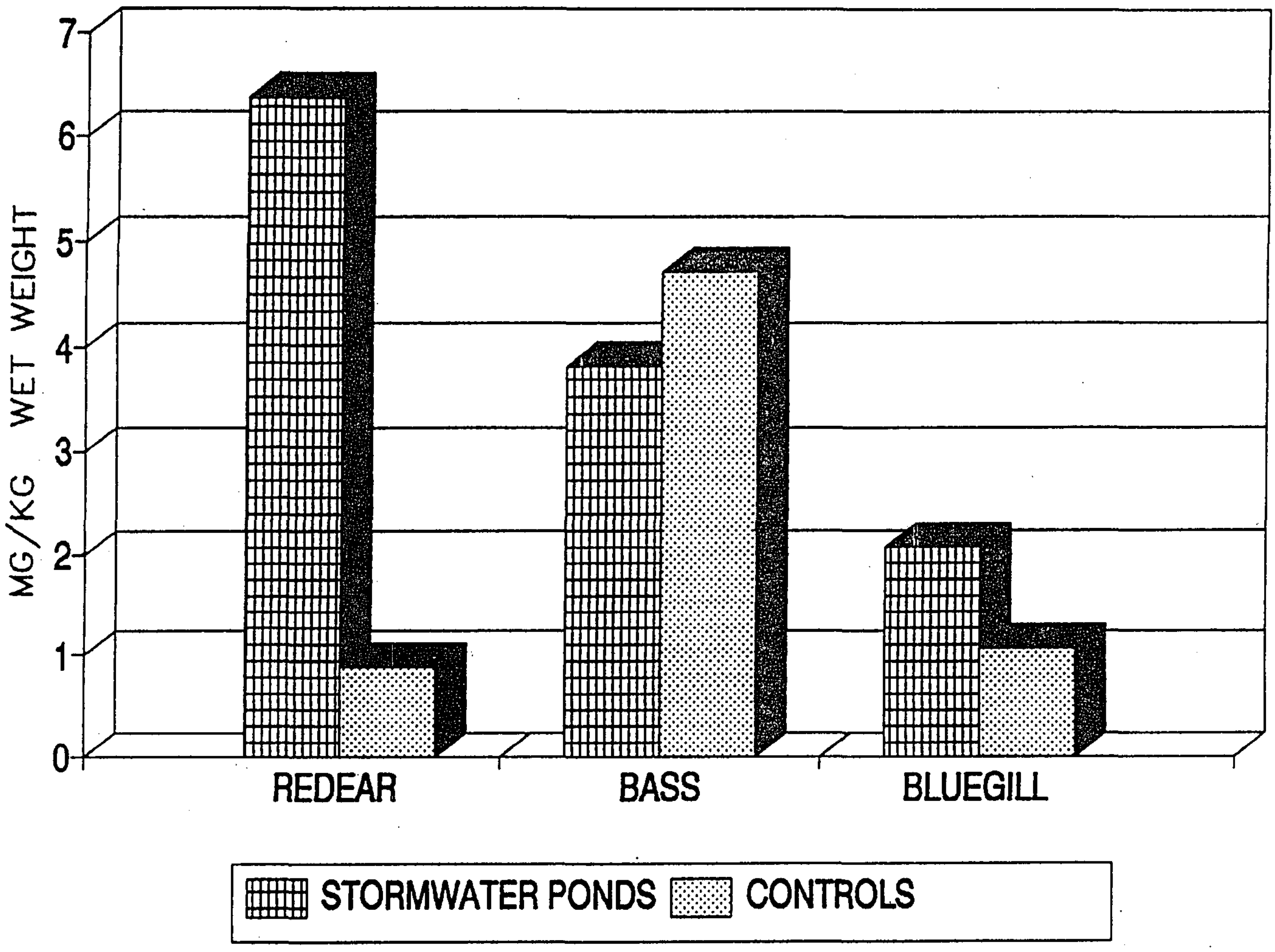

Figure 7. Mean copper concentrations of redear sunfish, *Lepomis microlophus*; largemouth bass, *Micropterus salmoides*; and bluegill sunfish, *Lepomis macrochirus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida

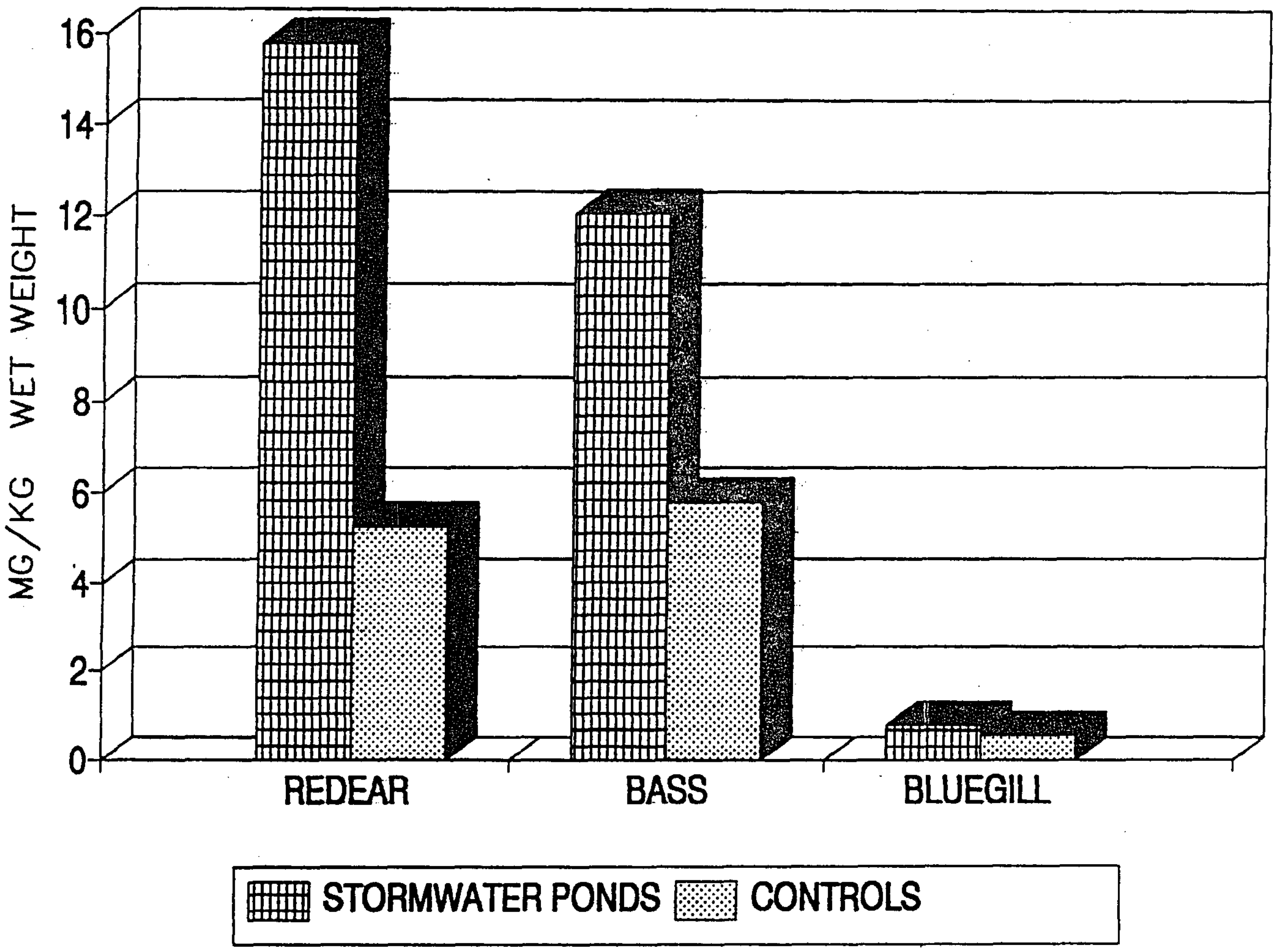

Figure 8. **Mean lead concentrations of redear sunfish, *Lepomis microlophus*; largemouth bass, *Micropterus salmoides*; and bluegill sunfish, *Lepomis macrochirus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida**

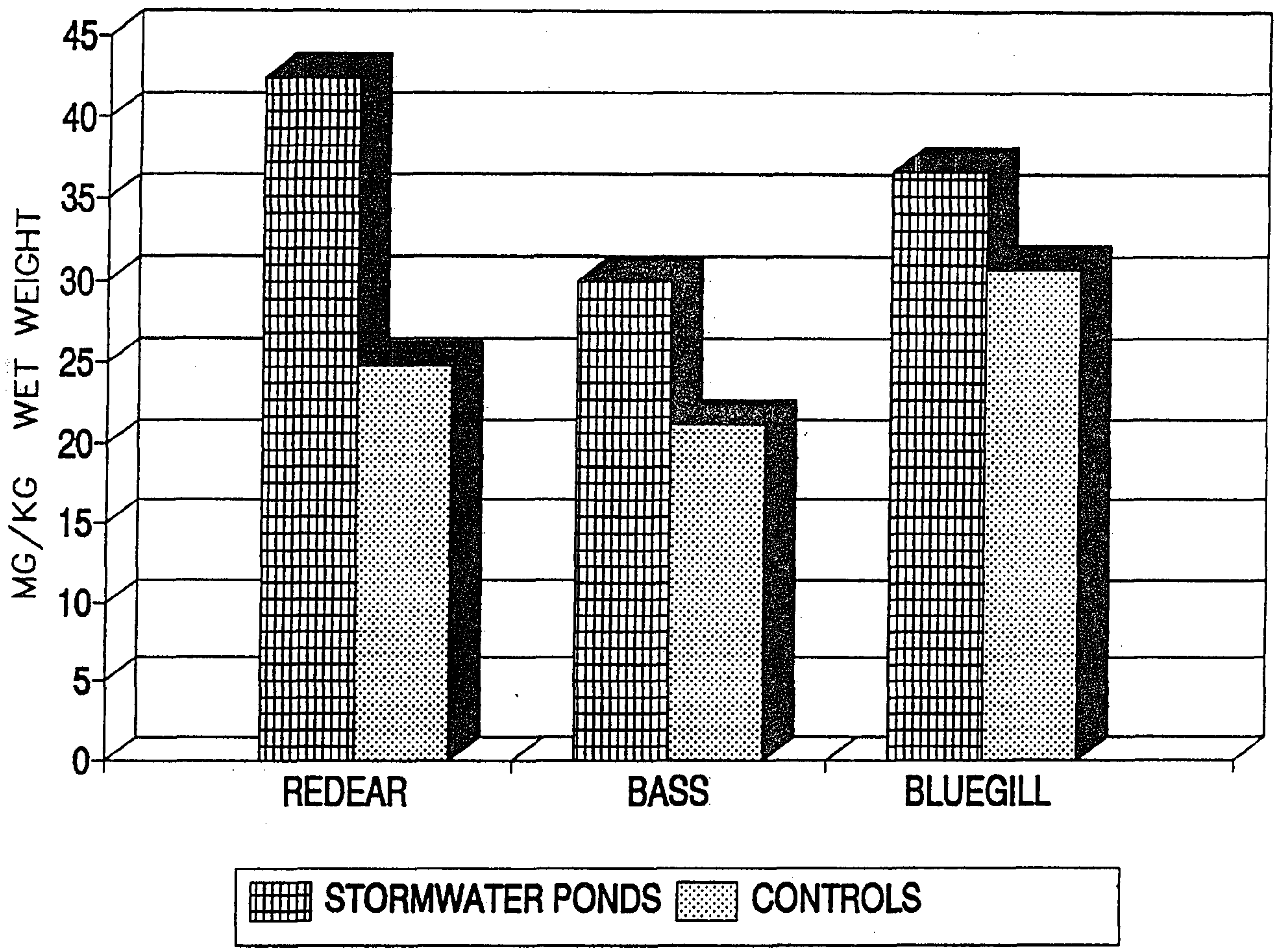

Figure 9. **Mean zinc concentrations of redear sunfish, *Lepomis microlophus*; largemouth bass, *Micropterus salmoides*; and bluegill sunfish, *Lepomis macrochirus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida**

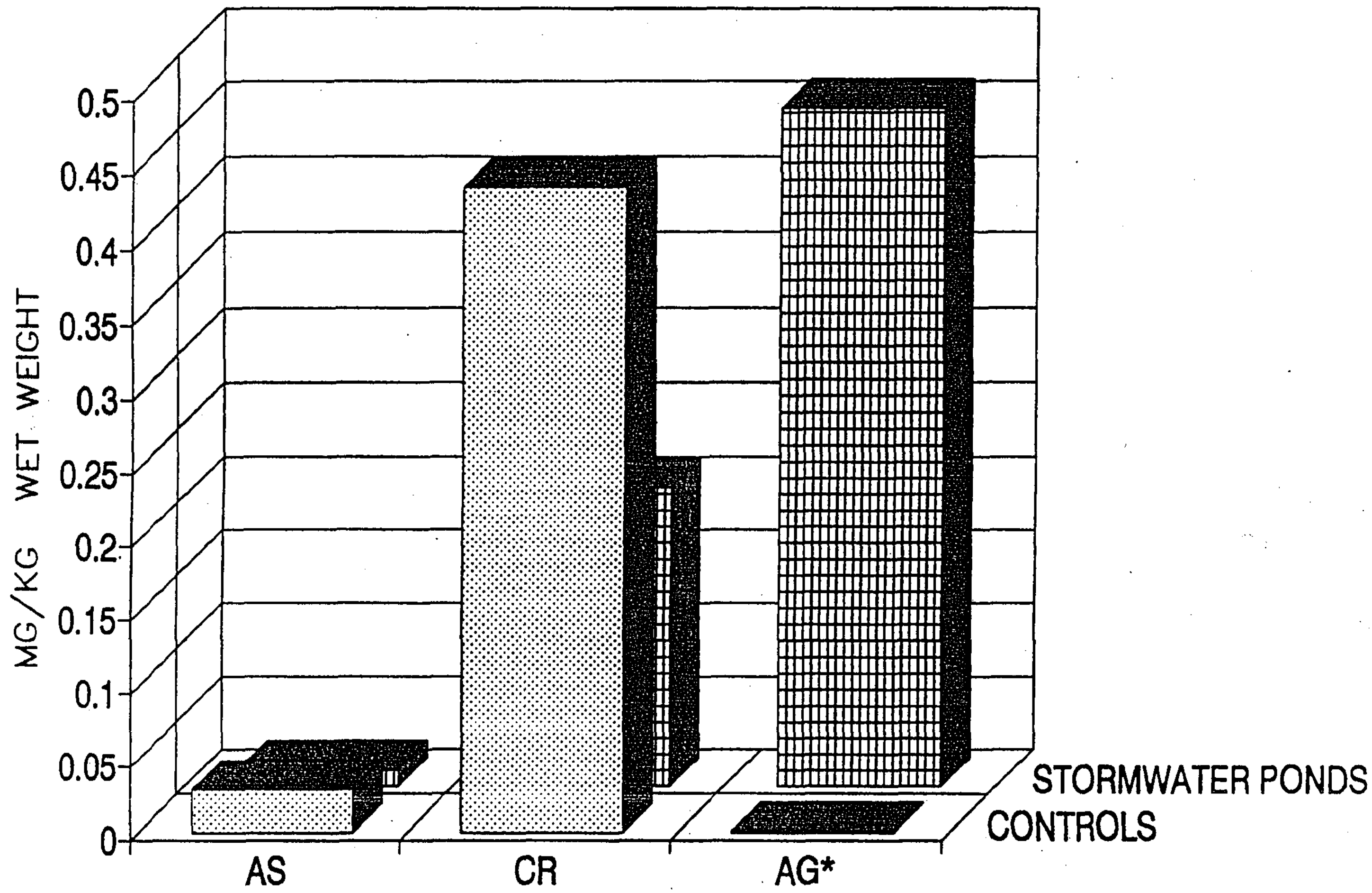

Figure 10. Mean arsenic, chromium, and silver concentrations of redear sunfish, *Lepomis microlophus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida. *Asterisk indicates significant difference at* p<0.005.

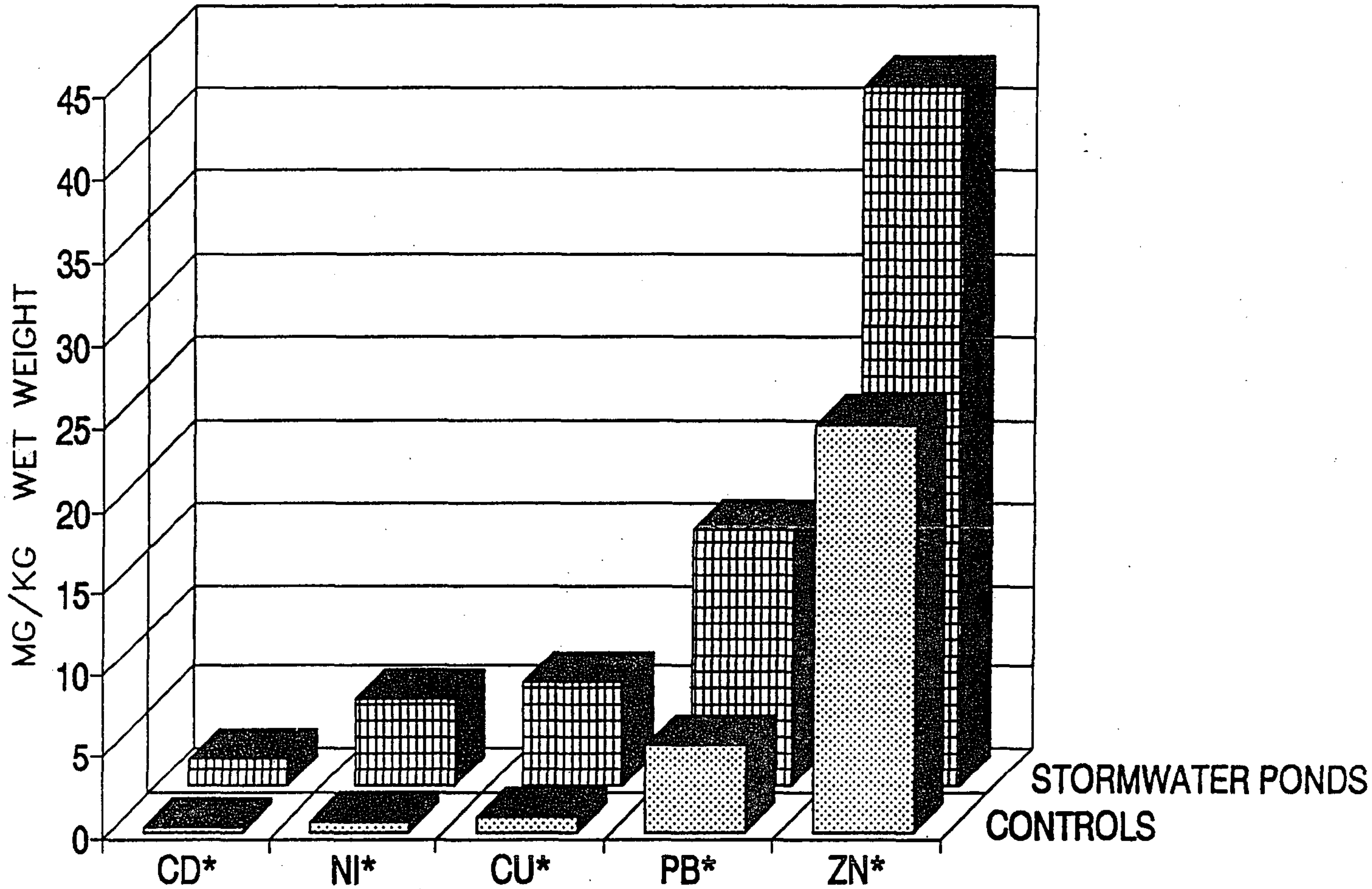

Figure 11. **Mean cadmium, nickel, copper, lead, and zinc concentrations of redear sunfish, *Lepomis microlophus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida.** *Asterisks indicate significant difference at* $p<0.005$.

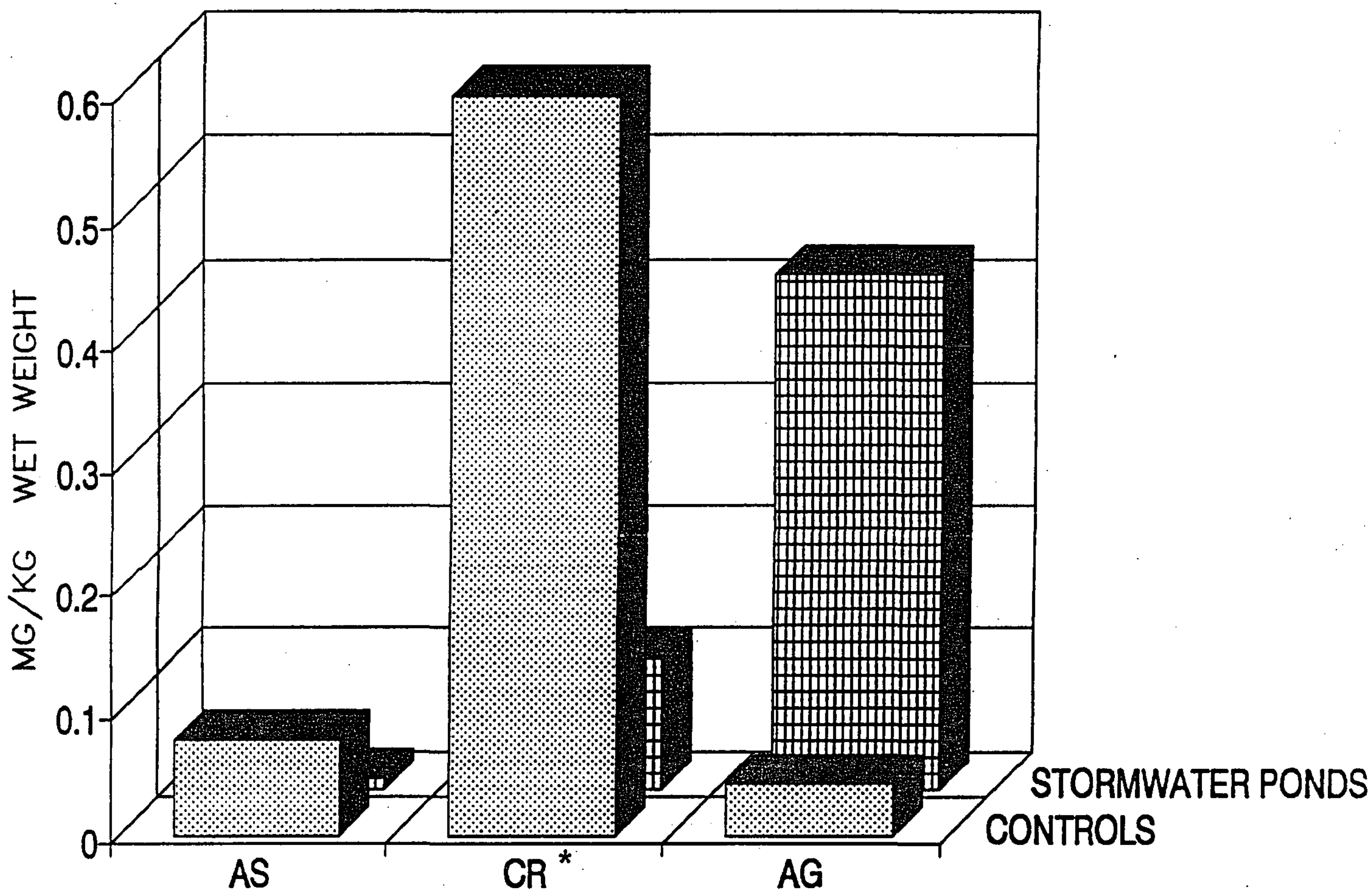

Figure 12. Mean arsenic, chromium, and silver concentrations of largemouth bass, *Micropterus salmoides*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida. *Asterisk indicates significant difference at* $p<0.005$.

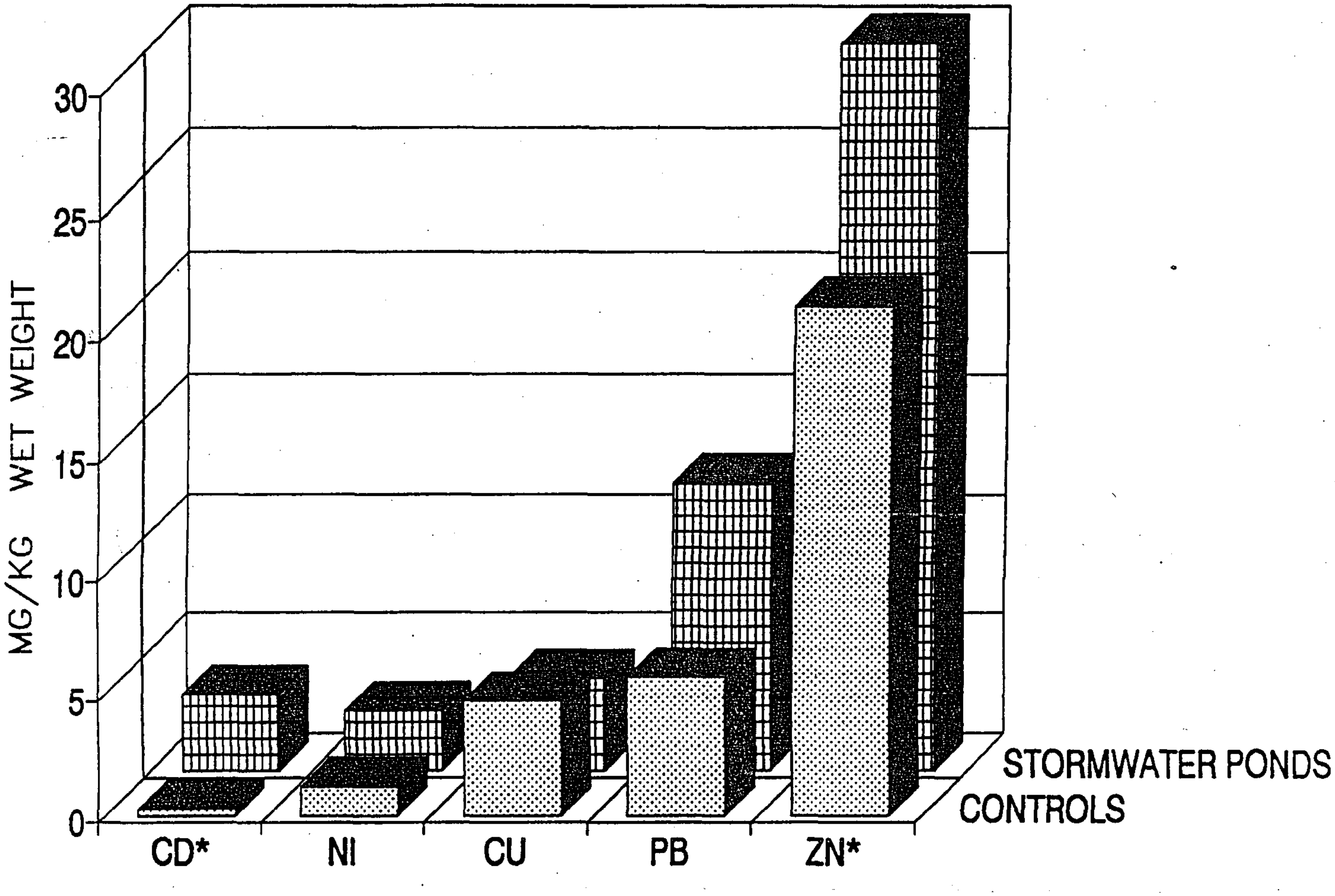

Figure 13. Mean cadmium, nickel, copper, lead, and zinc concentrations of largemouth bass, *Micropterus salmoides*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida. *Asterisks indicate significant difference at* p<*0.005.*

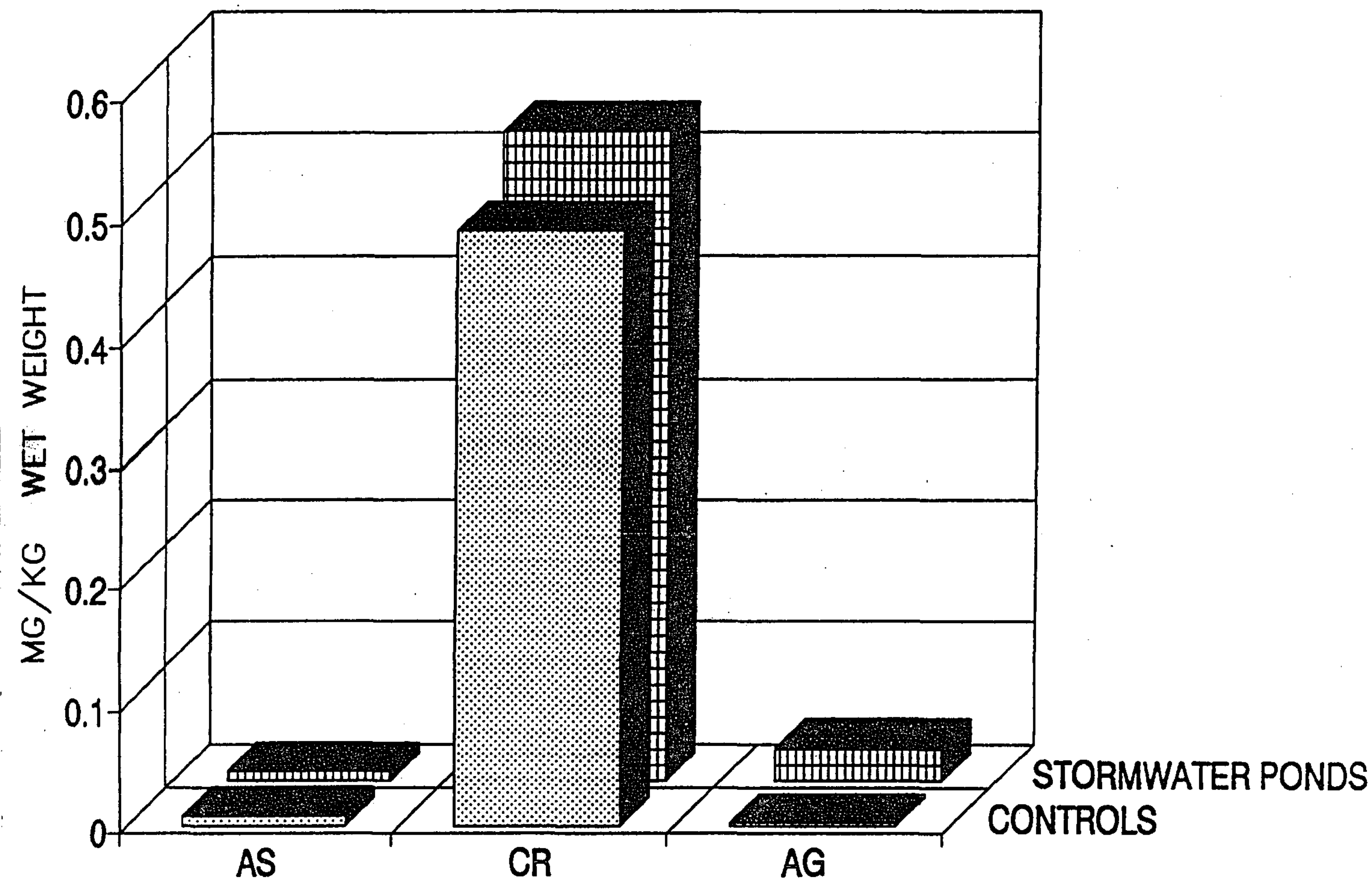

Figure 14. Mean arsenic, chromium, and silver concentrations of bluegill sunfish, *Lepomis macrochirus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida

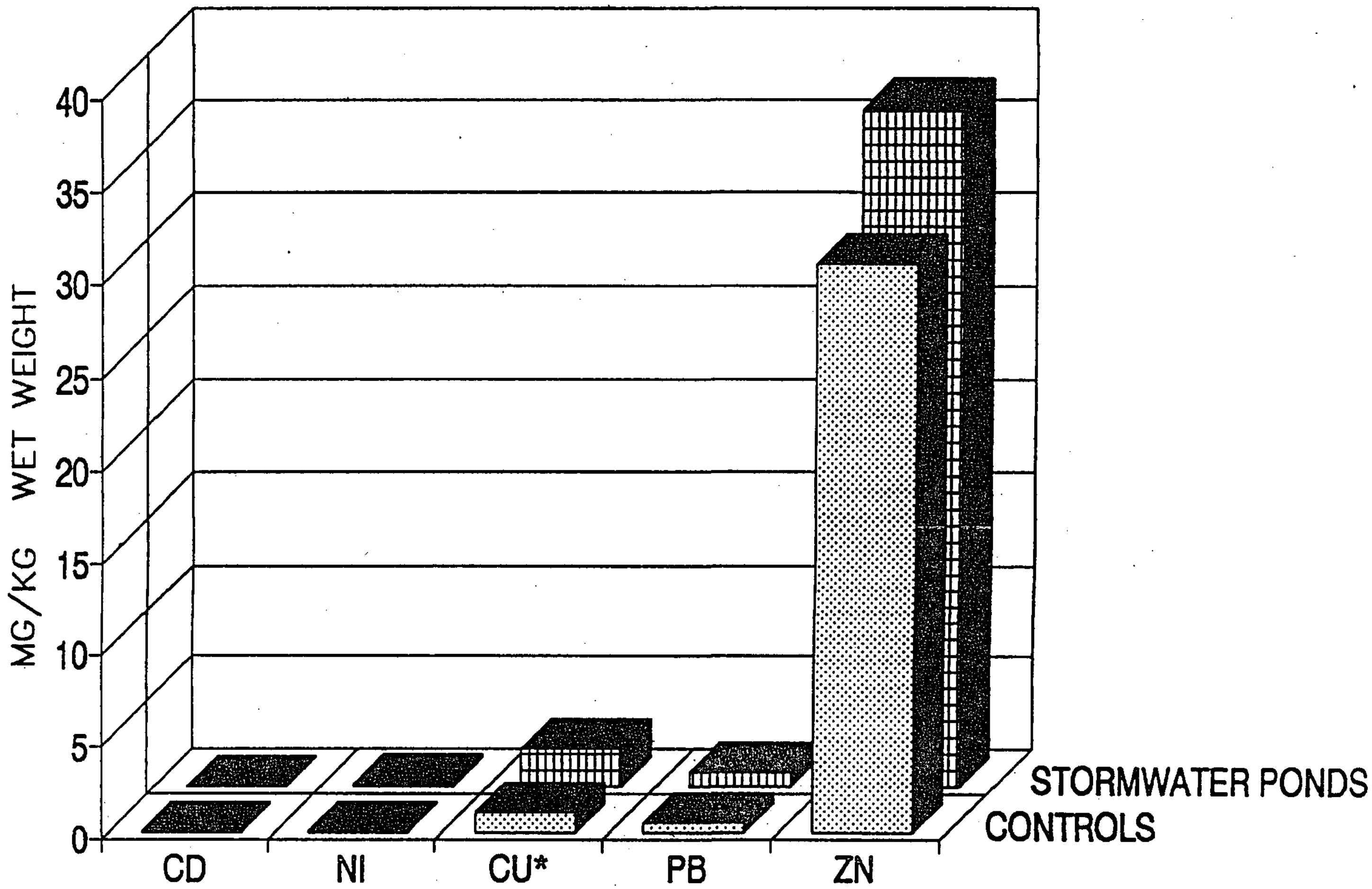

Figure 15. Mean cadmium, nickel, copper, lead, and zinc concentrations of bluegill sunfish, *Lepomis macrochirus*, collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida. *Asterisk indicates significant difference at* $p<0.005$.

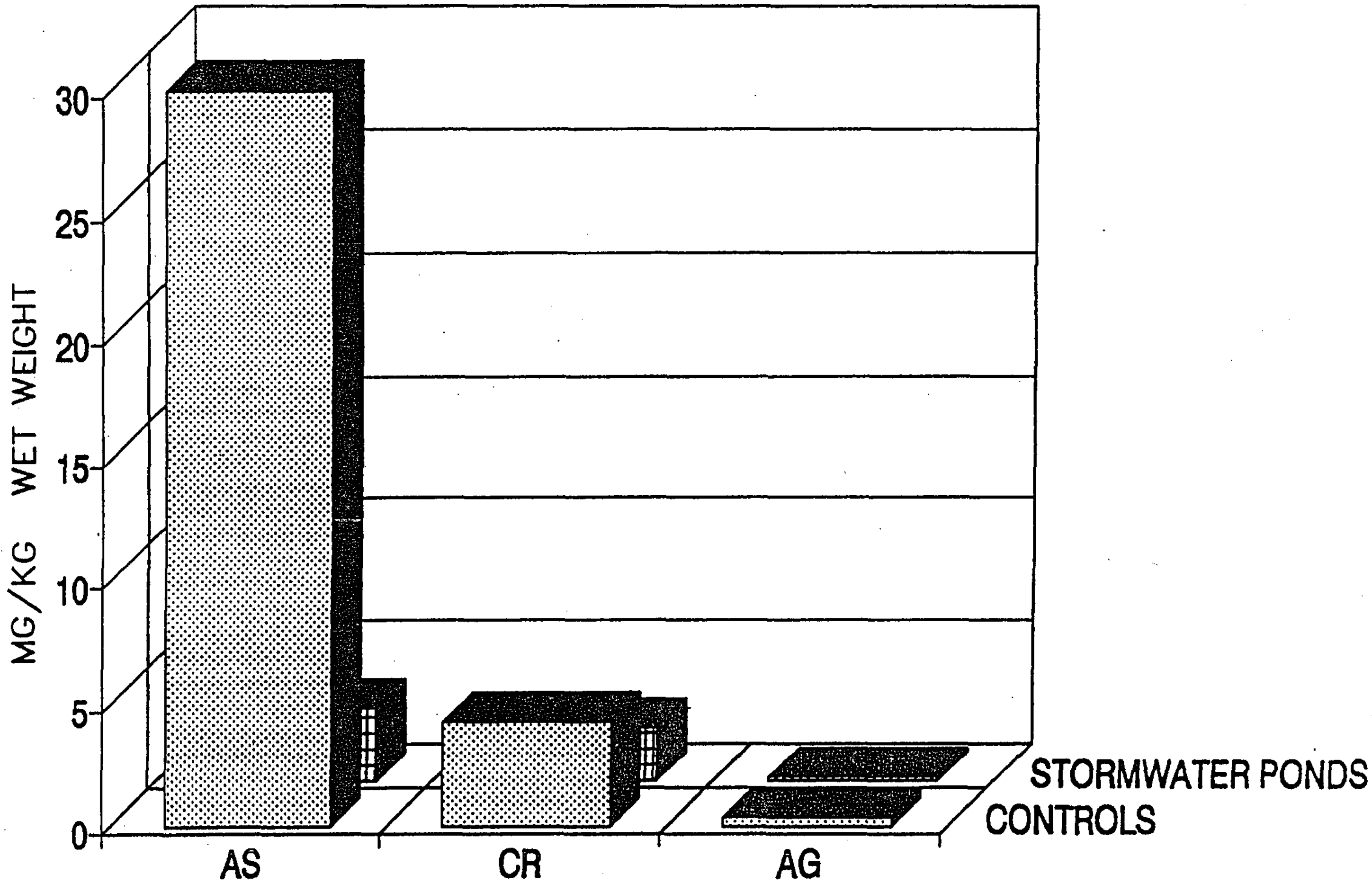

Figure 16. Mean arsenic, chromium, and silver concentrations of the composite sediment samples collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida

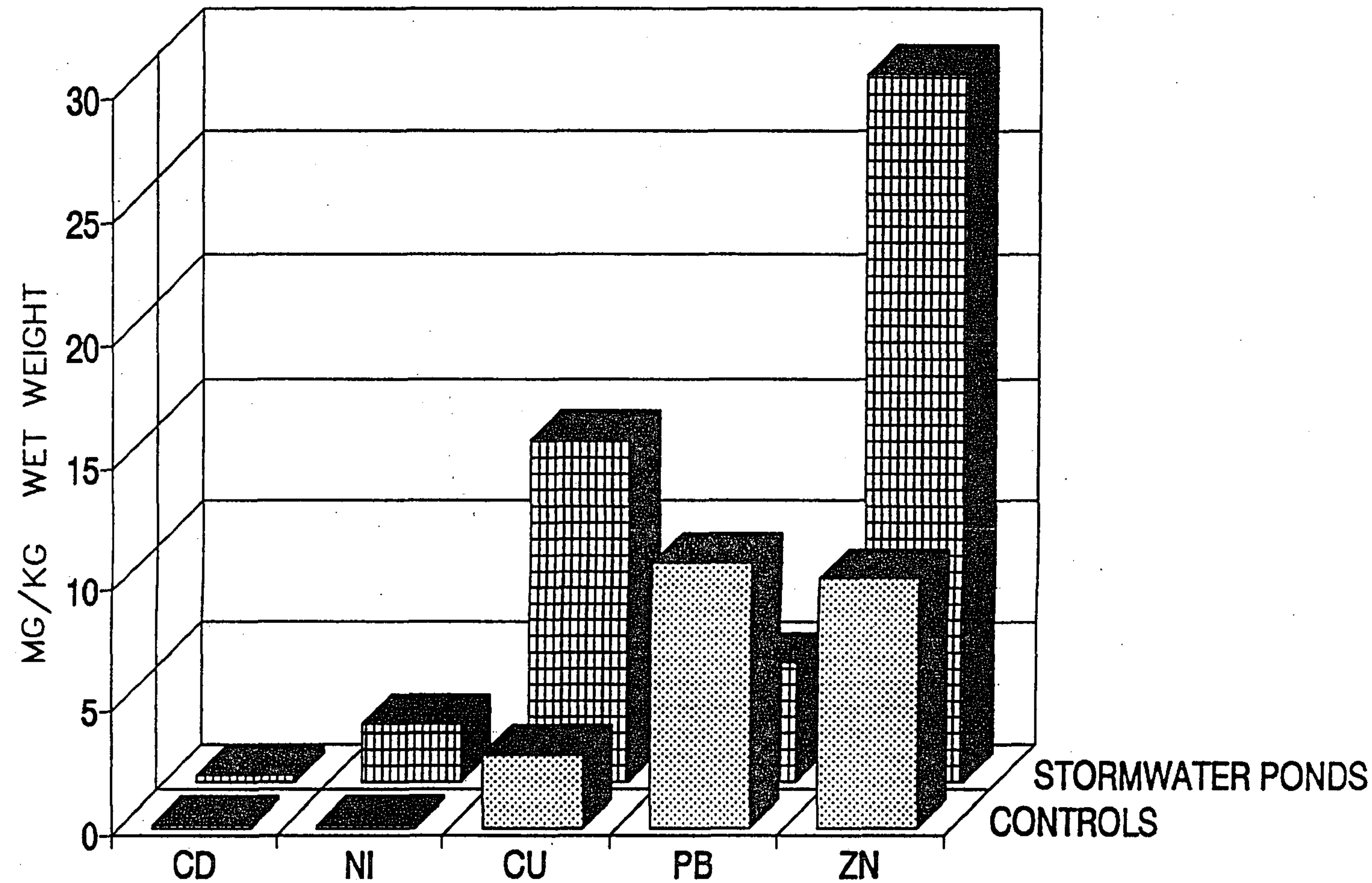

Figure 17. Mean cadmium, nickel, copper, lead, and zinc concentrations of the composite sediment samples collected from stormwater ponds and control sites, December 1991–March 1992, Orlando, Florida

DISCUSSION

ARSENIC

Based on the periodic classification of the elements, As is a semimetal, not a heavy metal. However, As has been included in the present study because of its toxicity and environmental consequences.

Arsenic may reach the aquatic environment through atmospheric fallout, industrial outfall, and the improper application of arsenical herbicides or pesticides (Sandhu 1977). Increased electricity production by coal-fueled electric power plants has increased production of As-contaminated particulate matter in the United States (Sorensen 1991). In the past in Florida, state agencies encouraged the use of As to control disease-causing ticks in cattle. Many of these former As "cattle dip" locations are now hazardous waste cleanup sites.

The control sites selected for the present study could receive As from herbicides, pesticides, former cattle dips, and/or atmospheric deposition from a coal-fueled power plant. These potential sources of As would account for the higher mean As concentrations in the redear sunfish, largemouth bass, and composite sediment samples collected from the control sites, as compared to those from the stormwater ponds (Table 14). Arsenic is not one of the most common metals found in stormwater runoff; if it is present, it is found in low concentrations (Nightingale 1987). Atmospheric deposition of As would not be as much of a factor in the stormwater ponds as compared to the control sites because the stormwater ponds, at the time of fish collection, were from 3 to 5 years old. The sediments in the much older control sites serve as a concentrated source of As, as indicated by the much higher concentration in the composite sediment samples.

Arsenic is one of the most toxic elements to fish (Sorensen 1991). Acute exposure can result in immediate death because of As-induced increases in mucus production, which causes suffocation or direct detrimental effects on the gill epithelium. In water, trivalent As (arsenite) is far more poisonous than the pentavalent form (arsenate); however, under aerobic conditions, arsenite quickly converts to arsenate. Stable, soluble inorganic arsenites and arsenates appear to be readily absorbed by the digestive tract, abdominal cavity, and muscle tissue (Forstner and Wittmann 1981). Arsenate is excreted more rapidly than arsenite, mostly in the urine. Arsenic may be methylated, much like mercury, to form highly toxic methylarsenic or demethylarsenic (*Trace metals: Unknown, unseen pollution threat* 1971; Braman and Foreback 1973). Arsenic is lipophilic; thus, fats contain more As than other tissue fractions.

Arsenic is accumulated by fish both from the water and from food. Reported As concentration factors are generally quite low. Arsenic does not appear to accumulate to as high a degree as other elements (Phillips and Russo 1978; Spehar et al. 1980). The mean As concentrations of the fish collected in the present study were the lowest (with the exception of Ag, in some cases) of the eight heavy metals surveyed. The lower accumulation of arsenicals than other metals in aquatic organisms is probably due to the complex transformations of As and is limited by excretion (Woolson 1977).

Wiebe et al. (1931) examined the background levels of As in largemouth bass from several Illinois rivers and then measured the accumulation of As by largemouth bass after exposure to As in food and water. Although As was readily accumulated from both sources, elimination was rapid upon the termination of exposure.

Gilderhus (1966) observed As uptake by young and adult bluegill sunfish placed in ponds treated with various concentrations of the herbicide sodium arsenite. Tissue residues of 1.3 and 5.0 mg/kg were associated with reduced growth rate and increased mortality in immature and adult bluegill sunfish, respectively.

Sorensen (1976) exposed green sunfish (*Lepomis cyanellus*) to various concentrations of As (as sodium arsenate) in water and measured the accumulation of the metal. There appeared to be a relationship between exposure concentration and the amount of As accumulated, but the data were quite scattered. Whole body uptake of As by fish is a function of exposure concentration and exposure time (Sorensen 1991).

The U.S. Food and Drug Administration (FDA) allows 3.5 mg/kg of As in fruits and vegetables, and Canada recommends a maximum level of 5.0 mg/kg for food (NAS 1973). The mean As concentrations of the fish collected in the present study were lower than these values.

Because the mean As concentration of largemouth bass collected from the control sites was the highest of the fish sampled, the results suggest that biomagnification may be occurring. This concept does not agree with the literature. Sorensen (1991) reported that the association of fish with sediments can alter As accumulation, with bottom feeders accumulating the highest As levels. Woolson (1977), in a review of the bioaccumulation of arsenicals, similarly reported that As is bioconcentrated by aquatic organisms but not biomagnified. In a study done by Foley et al. (1978), no magnification of As was evident between fish trophic levels. Ellis et al. (1941) found that largemouth black bass from the southern United States retained up to 40 mg/kg of As; this is much higher than values reported in other studies. Largemouth bass collected from the control sites may have been able to accumulate higher mean As concentrations. Insufficient data are available to evaluate why the largemouth bass collected from the control sites had higher mean As concentrations than the other two species.

The mean As concentration of redear sunfish, the bottom feeder, collected from stormwater ponds was slightly higher than that of the other two species, a finding that is consistent with many other studies.

The mean As concentrations of the fish collected in the present study were within the range of values reported in other studies. Foley et al. (1978) collected fish from Chautauqua Lake, New York, that contained 0.20–2.04 mg/kg of As. Largemouth bass contained 0.04–0.10 mg/kg of As, and bluegill sunfish contained 0.06–0.24 mg/kg of As (Foley et al. 1978). Ellis et al. (1941) surveyed the As content of various freshwater fish species collected from waters in the southeastern United States; the average content for all species was 0.75 mg/kg of As. Whole body levels of As in fish from across the United States from 1978 to 1981 were from 0.14 to 0.16 mg/kg (Lowe et al. 1985). The average concentration of As was 0.016 mg/kg for three species collected from three of the Great Lakes (Lucas et al. 1970).

No significant correlation was observed between the mean As concentration and the length and weight of the redear sunfish, largemouth bass, and bluegill sunfish. This lack of a correlation was consistent with results obtained in other studies. Arsenic accumulation has been found to be uncorrelated with fish total length, dry weight, wet weight, or condition factors (Sorensen 1976, 1991). Accumulation of the metal is considered a function of the detoxification and clearance roles of individual organs (Sorensen et al. 1979). Hunter et al. (1981) determined that the lack of correlation between fish length and As concentration indicates that the maximum amount accumulated is limited, probably by excretion. This lack of a correlation between metal parameters and fish weight might be due, in part, to the fact that nonessential elements, such as As, are merely contaminations of tissue, and these elements have no significant function (Liebscher and Smith 1968).

CHROMIUM

Chromium is one of the least toxic of the trace elements on the basis of its oversupply and essentiality (Forstner and Wittmann 1981). It is toxic in high concentrations; toxicity varies with oxidation state. Trivalent Cr is moderately toxic to organisms, whereas hexavalent Cr is highly toxic (Bowen 1966). Chromium is required in extremely minute quantities by mammals; however, its essentiality for fish apparently has not yet been determined (Giesy and Wiener 1977). Fish are known to reach an equilibrium concentration of Cr, but the time to reach equilibrium varies (Phillips and Russo 1978). What is clear from these studies is that following exposure, fish rapidly eliminate Cr upon return to uncontaminated water. Thus, fish exposed intermittently to high Cr levels would not experience cumulative uptake. Chromium in fish apparently is accumulated from water through the gills, followed by transport via the blood to the various organs and tissues. The metal eventually reaches the gut, where it is eliminated through the feces.

The usual sources of Cr (e.g., stormwater runoff) seem contradictory to the fact that redear sunfish collected from the control sites contained a higher mean Cr concentration than redear sunfish collected from the stormwater ponds, and that largemouth bass collected from the control sites contained a significantly higher ($p<0.005$) mean concentration than largemouth bass collected from the stormwater ponds (Table 14). The hypothesis was that all species of fish collected from the stormwater ponds would contain higher mean concentrations of Cr than fish collected from the control sites.

Atmospheric deposition of Cr can occur as a result of coal-fueled power plants, however (Dr. A. Keller, pers. comm. 1993). Atmospheric deposition may explain why the two species of fish and the sediment samples collected from the control sites contained a higher mean Cr concentration than those from the stormwater ponds.

All available evidence suggests that Cr is not biomagnified (Nriagu and Nieboer 1988). The results of the present study suggest biomagnification, however, because the largemouth bass collected from the control sites contained the highest mean Cr concentration of the fish sampled, and the mean concentrations were significantly higher than that in largemouth bass collected from the stormwater ponds.

Of the fish collected from stormwater ponds, the bluegill sunfish contained the highest mean Cr concentration (Table 14). This finding is consistent with a study done by Mathis and Cummings (1973), in which ten freshwater fish species from the Illinois River were collected. They showed that omnivorous species had significantly higher Cr concentrations in the muscle than carnivorous species, implying that diet was responsible for the observed differences.

Wiener et al. (1982) indicated that levels $\geq$3.5 mg/kg in whole bluegill sunfish possibly represented elevated concentrations, whereas Eisler (1986) indicated that tissue levels >4.0 mg/kg should be viewed as presumptive evidence of Cr contamination. The mean Cr concentration of bluegill sunfish collected from the stormwater ponds and control sites was lower than either of these values.

Reported total Cr concentrations in freshwater fish generally average less than 1 mg/kg (Cushing and Watson 1972; Mathis and Cummings 1973; NAS 1974; Tong et al. 1974; Giesy and Wiener 1977). Mean Cr concentrations of the three species collected from stormwater ponds and control sites were less than 1.0 mg/kg.

The mean Cr concentrations of the three species of fish collected in the present study were within the range of values obtained in many other studies (Appendix). Bluegill sunfish collected from Par Pond, South Carolina, contained this metal in a concentration of 0.04 mg/kg (Giesy and Wiener 1977). Elwood et al. (1980) found that the mean Cr concentration of bluegill sunfish from contaminated White Oak Lake was 1.22 mg/kg and that of largemouth bass was 0.38 mg/kg. The average Cr concentration of bluegill sunfish collected from uncontaminated Melton Hill Reservoir was 0.73 mg/kg; largemouth bass from this reservoir had a mean Cr concentration of 0.53 mg/kg. Bluegill sunfish from the Wilson Reservoir, Alabama, had a Cr concentration of

0.64 mg/kg; largemouth bass from the reservoir had a mean Cr concentration of 0.37 mg/kg (Dycus 1986). Redear sunfish from Pickwick Reservoir, Alabama, had a mean Cr concentration of 5.25 mg/kg; the mean concentration of the bass was 7.02 mg/kg, and that of the bluegill sunfish was 0.75 mg/kg (Dycus 1986). Bluegill sunfish from the Upper Mississippi had a mean Cr concentration of 0.87 mg/kg (Wiener et al. 1982). Mathis and Cummings (1973) recorded the average Cr concentration of largemouth bass from the Illinois River as 0.11 mg/kg.

In the present study, no significant correlation was observed between the mean Cr concentration and the length or weight of any species. These results are consistent with other studies. Elwood et al. (1980) reported a negative correlation between the metal concentration and fish weight. Seenayya and Prahalad (1987) also found that the concentration decreased with the increase in body weight of the fish. In a study by Tong et al. (1974), Cr content increased with age in lake trout. Correlations between the whole body concentration and the fish total length were nonsignificant in a study done by Giesy and Wiener (1977).

SILVER

Silver is one of the most toxic but least studied of the heavy metals in aquatic ecosystems (Coleman and Cearley 1974). Although Ag has received little environmental attention, it is a very toxic metal, it occurs in industrial discharges, and it must be considered in any classification of highly toxic pollutants (Bowen 1966). Silver, in minute amounts in water, is very toxic to fish. It probably interferes with gas exchange in the gills (Gough et al. 1979). Most of the soluble Ag ingested remains impregnated in tissues, forming a stable bond (Forstner and Wittmann 1981). Birge et al. (1978) found the metal to be among the most toxic to largemouth bass and rainbow trout.

Coleman and Cearley (1974) found that the rate of weight gain of largemouth bass and bluegill sunfish exposed to Ag decreased as concentrations increased; bass were more sensitive to Ag than were bluegill sunfish. Bass and bluegill sunfish accumulated Ag in concentrations greater than were present in water, with a subsequent equilibrium developing between water and tissue concentrations. Abnormal behavior was observed in both species. Metal accumulations in bass tissues were highest in the internal organs, followed by the gills and remainder of the body.

As indicated by the results of the present study, Ag was present in the stormwater ponds and bioaccumulated in the fish that live in these ponds (Table 14). This accumulation of Ag in fish collected from the stormwater ponds was consistent with many other studies. Redear sunfish, which are most associated with the bottom sediments, contained the highest metal concentration of the fish sampled and had significantly higher concentrations than redear sunfish collected from the control sites. Largemouth bass collected from the stormwater ponds did not contain a statistically elevated ($p>0.005$) mean Ag concentration, although the actual p value (0.0057) indicated that the difference was biologically meaningful. Bluegill sunfish collected from the stormwater ponds also contained a higher mean concentration than control site fish; however, the difference was not statistically significant. There were no values of Ag concentration in fish available in the literature with which to compare the results. Therefore, it is not known whether the mean Ag concentrations of fish collected from the stormwater ponds represented high levels.

The lack of a significant correlation between the mean Ag concentration and the length and weight of redear sunfish, largemouth bass, and bluegill sunfish was consistent with the literature regarding other heavy metals. The literature did not contain Ag values for fish and, therefore, no relevant comparison could be made.

CADMIUM

Cadmium is nonessential and highly toxic (Fleischer et al. 1974). If present in sufficient quantities in consumed products, it causes kidney failure in humans and "itai-itai" disease, a painful skeletal deformity first recorded in Japan (Suffern et al. 1981). Cadmium may replace Zn in certain enzymes, causing disease (Lagerwerff 1972). Hiltibran (1971) reported that the metal severely limited oxygen metabolism of mitochondria in the liver of bluegill sunfish. Cadmium is known to accumulate in the gill, liver, and kidney of fish (Sorensen 1991).

Cearley and Coleman (1974) exposed bluegill sunfish and largemouth bass to subacute levels of Cd and found that fish accumulated equilibrium concentrations within 2 months. They suggested that an elimination system was activated to equilibrate elimination and uptake after a threshold concentration was reached in the body. This process may be of significance in limiting body burdens of nonessential heavy metals.

The mean Cd concentrations of redear sunfish and largemouth bass in the present study were compared to values obtained in a similar study conducted by Murphy et al. (1978b). The data show that mean Cd concentrations in redear sunfish collected from stormwater ponds were similar to values obtained for redear sunfish from a contaminated system in Indiana (Table 15). Redear sunfish collected from control sites contained higher mean concentrations than values obtained from an uncontaminated system in Indiana. The uncontaminated system in Indiana appeared to be more pristine or unpolluted than the controls used in the present study. Cadmium concentrations obtained for redear sunfish collected in the present study were similar to those obtained in similar studies (Sorensen 1991).

The mean Cd concentration of largemouth bass collected from stormwater ponds was much higher than values obtained in Indiana (Table 15). Largemouth bass collected from the control sites had mean concentrations similar to values obtained from the contaminated system in Indiana. Largemouth bass collected from stormwater ponds also had mean concentrations higher than those obtained in similar studies (Sorensen 1991).

The mean Cd concentration of the bluegill sunfish collected from the stormwater ponds was lower than the range of values obtained for bluegill sunfish in similar studies (Table 16). Bluegill

Table 15. Mean whole body concentrations of cadmium (mg/kg wet weight) in redear sunfish, *Lepomis microlophus*, and largemouth bass, *Micropterus salmoides*, collected in two studies

Location	Cadmium Concentration	Number of Fish	Reference
Redear Sunfish			
Contaminated Systems			
Stormwater ponds, Orlando, Florida	1.640	15	This study
West Basin, Palestine Lake, Indiana	2.000	10	Murphy et al. 1978b
Uncontaminated Systems			
Control sites, Orlando, Florida	0.198	15	This study
East Basin, Palestine Lake, Indiana	0.032	9	Murphy et al. 1978b
Largemouth Bass			
Contaminated Systems			
Stormwater ponds, Orlando, Florida	3.160	15	This study
West Basin, Palestine Lake, Indiana	0.277	33	Murphy et al. 1978b
Uncontaminated Systems			
Control sites, Orlando, Florida	0.241	15	This study
East Basin, Palestine Lake, Indiana	0.030	17	Murphy et al. 1978b

sunfish collected from the control sites in the present study contained a lower mean concentration than values obtained for the species from one uncontaminated system.

Table 16. Mean whole body concentrations of cadmium (mg/kg wet weight) in bluegill sunfish, *Lepomis macrochirus*, collected in various studies

Location	Cadmium Concentration	Number of Fish	Reference
Contaminated Systems			
Stormwater ponds, Orlando, Florida	0.0058	15	This study
West Basin, Palestine Lake, Indiana	0.7800	35	Murphy et al. 1978b
Palestine Lake, Indiana	0.8500	35	Atchison et al. 1977
Fox River, Illinois	0.0500	61	Vinikour et al. 1980
Skinface Pond, South Carolina	0.0700	12	Wiener and Giesy 1979
Little Center Lake, Indiana	0.0900	40	McIntosh and Bishop 1976
Upper Mississippi River	0.0100	11	Wiener et al. 1982
Par Pond, South Carolina	0.0700	35	Giesy and Wiener 1977
Uncontaminated Systems			
Control sites, Orlando, Florida	0.0036	15	This study
East Basin, Palestine Lake, Indiana	0.0250	31	Murphy et al. 1978b

The degree of association of fish with sediments seems to play a critical role in Cd accumulation. For example, higher whole body levels are observed in benthic fish species than they are in pelagic fish species (Ney and Van Hassel 1983). Murphy et al. (1978b) determined that diet influenced Cd accumulation in fish. Comparison of Cd levels in redear sunfish (a snail-eater) with those of bluegill sunfish showed an almost three-fold higher concentration in the redear sunfish. Carnivorous largemouth bass contained among the lowest whole body trace metal concentrations, whereas the more omnivorous bluegill sunfish generally contained higher concentrations.

In the present study, redear sunfish collected from the stormwater ponds and control sites contained much higher mean Cd concentrations than bluegill sunfish, a finding that is consistent with other studies. Largemouth bass collected from the stormwater ponds, however, contained the highest mean concentration. Either the diet of the largemouth bass in the present study was different from bass collected in similar studies or other factors were involved. The bass in central Florida may eat more insects and crustaceans than bass from the Midwest; this could explain the higher mean Cd concentrations in the fish in the present study. The diet of the bluegill sunfish in central Florida may contain less vegetation than in other parts of its range; this could explain the low mean concentrations when compared with other studies.

Wiener and Giesy (1979) determined that trace metal concentrations in fish are apparently related to factors other than food habits and trophic status. The authors documented significant differences in trace metal concentrations in pickerel and largemouth bass, both of which occupy the highest trophic level. Both species have similar dietary preferences. The authors suggested that numerous factors, including source, exposure level, distance from contamination source, and the presence of other ions, play a role in determining the level of accumulated Cd. These other factors may explain why largemouth bass in the present study contained higher mean Cd concentrations than bass in similar studies, or why the mean concentration was higher than that of the redear sunfish, the bottom feeder. These factors also may explain why bluegill sunfish contained fairly low mean Cd concentrations.

The fish collected from the stormwater ponds contained more Cd (significantly more at a $p<0.005$ in the cases of redear sunfish and largemouth bass) than those from the control sites (Table 14). These results were similar to a study done by Murphy et al. (1978a), where concentrations of Cd in muscles were significantly greater in samples of largemouth bass and bluegill sunfish from a contaminated site than in corresponding samples from an uncontaminated site in Palestine Lake, Indiana.

The FDA standard for Cd is 5 mg/kg (Suffern et al. 1981). The mean Cd concentrations of the fish in the present study did not exceed the FDA value. In contrast, Canada has a 0.5 mg/kg standard of Cd for consumption of fish (Dycus 1986). The mean Cd concentrations of redear sunfish and largemouth bass collected from the stormwater ponds exceeded the Canadian value.

No significant correlation was observed between the mean Cd concentration and the length and weight of redear sunfish, largemouth bass, or bluegill sunfish. This lack of a correlation was consistent with results obtained in other studies (Lovett et al. 1972; Havre et al. 1973; Giesy and Wiener 1977; Murphy et al. 1978b; Wiener and Giesy 1979; Kent and Johnson 1979; Vinikour et al. 1980).

NICKEL

Nickel is thought to be essential for some plants and animals (Gough et al. 1979). Because of its low toxicity to humans, little information is available in the literature concerning the accumulation of Ni by aquatic animals. Nickel may be harmful to the survival and productivity of freshwater fauna, thereby disturbing the natural ecosystem and its food chains (Moore and Ramamoorthy 1984). Nickel is toxic to algae and fish (Suffern et al. 1981). In excess, Ni interferes with the detoxification activities of the liver (Mastromatteo 1986). Nickel is seldom a problem in aquatic biota except in cases of extreme pollution (Moore and Ramamoorthy 1984). Sreedevi et al. (1992) reported that freshwater fish accumulated significant Ni when exposed to sublethal concentrations. Tjalve et al. (1988) showed that fish bioaccumulate moderate amounts of Ni from water.

The mean Ni concentrations of the fish in the present study were within the range of values reported in similar studies. The reported range of Ni is 0.2–2.0 mg/kg (Jenkins 1980) for uncontaminated areas in whole fish. Uthe and Bligh (1971) found very low levels for Ni (0.2 mg/kg) in seven fish species from contaminated and uncontaminated areas. Mathis and Cummings (1973) found from 0.04–0.52 mg/kg Ni in the muscles of several species of fish from the Illinois River. Nickel concentrations in fish from Pickwick Reservoir, Alabama, were as follows: largemouth bass, 6.4 mg/kg; bluegill sunfish, 0.75 mg/kg; redear sunfish, 7.6 mg/kg (Dycus 1986). The average Ni concentration of largemouth bass from Wilson Reservoir, Alabama, was 5.25 mg/kg; bluegill sunfish had Ni concentrations of 7.42 mg/kg (Dycus 1986).

The bioaccumulation pattern of Ni in the present study was consistent with similar studies on Ni and other heavy metals, that is, those species most associated with the bottom sediments contained the highest concentration of Ni. Redear sunfish, the bottom feeder, collected from stormwater ponds contained the highest Ni concentration of any of the fish species. Largemouth bass collected from stormwater ponds had the second highest Ni concentration, followed by bluegill sunfish. All three species collected from stormwater ponds had higher Ni concentrations than those from the control sites (significantly higher in the redear sunfish) (Table 14).

The National Research Council (1975) found that most foods (including clams, scallops, shrimp, lobsters, crab, marine fishes, and freshwater fishes) contain Ni levels below 0.75 mg/kg. However, the mean concentrations of Ni were higher than 0.75 mg/kg for the redear sunfish collected from the stormwater ponds and largemouth bass collected from the stormwater ponds and control sites.

No significant correlation was observed between the mean Ni concentration and the length and weight of any of the three fish species, a result consistent with Wren et al. (1983).

COPPER

Copper is a known essential trace element for plants and animals (Gough et al. 1979). It can be acutely toxic at high concentrations (Giesy and Wiener 1977). For aquatic organisms, Cu is the most toxic of the common heavy metals. Cu (as copper sulfate) is commonly used as an algicide. From the standpoint of human health, Cu is relatively low in toxicity compared to metals such as mercury and Cd, although prolonged consumption of large doses has been known to cause emesis and liver damage (NAS 1973).

Several effects of exposure to sublethal concentrations of Cu have been reported in fish. These effects include decreased survival, growth, and reproduction (Mount and Stephan 1969; McKim and Benoit 1971). In addition, fish exposed to sublethal concentrations accumulate Cu in certain tissues, particularly the gills and liver (Brungs et al. 1973; Benoit 1975). The liver is a vital organ in maintaining internal Cu homeostasis; the teleost liver actively processes and stores large Cu loads (Sorensen 1991). Felts and Heath (1984) found that Cu caused a decrease in whole body oxygen consumption in bluegill sunfish. The large number of Cu-containing enzymes and glycoproteins in fish probably accounts for the diversity of biological effects (Sorensen 1991).

The mean Cu concentrations of fish collected in the present study were compared to values obtained in similar studies (Table 17).

Redear sunfish collected from stormwater ponds had a mean Cu concentration that was higher than that reported in other studies. Concentrations of Cu in redear sunfish collected from the control sites were within the range of other reported values. Largemouth bass collected from the stormwater ponds and control sites had mean Cu concentrations that were consistent with results from other studies. The mean Cu concentration of bluegill sunfish collected in the present study was similar to other reported values.

Elevated levels of Cu in fish tissues are associated with the development of an enhanced tolerance to subsequent Cu

Table 17. Mean whole body concentrations of copper (mg/kg wet weight) in various fish species collected in various studies

Location	Species	Copper Concentration	References
Stormwater ponds, Orlando, Florida	Redear sunfish	6.37	This study
Control sites, Orlando, Florida	Redear sunfish	0.88	This study
Pickwick Reservoir, Alabama	Redear sunfish	5.62	Dycus 1986
Stormwater ponds, Orlando, Florida	Largemouth bass	3.81	This study
Control sites, Orlando, Florida	Largemouth bass	4.71	This study
Pickwick Reservoir, Alabama	Largemouth bass	6.60	Dycus 1986
Wilson Reservoir, Alabama	Largemouth bass	4.75	Dycus 1986
Stormwater ponds, Orlando, Florida	Bluegill sunfish	2.08	This study
Control sites, Orlando, Florida	Bluegill sunfish	1.07	This study
Wilson Reservoir, Alabama	Bluegill sunfish	5.58	Dycus 1986
Pickwick Reservoir, Alabama	Bluegill sunfish	8.25	Dycus 1986
Par Pond, South Carolina	Bluegill sunfish	0.55	Giesy and Wiener 1977
Three Great Lakes	Three species	1.30	Lucas et al. 1970
United States	Many species	0.86	Lowe et al. 1985

exposure (Dixon and Sprague 1981). This concept may explain the elevated concentrations in largemouth bass collected from the control sites. Fish collected from the control sites may previously have been exposed to Cu (possibly from Cu-based herbicides and pesticides) and developed an enhanced tolerance.

Mathis and Cummings (1973) reported high Cu concentrations in sediments and in animals living in or on the sediments. The concentration of most metals in tissue appears to be more greatly influenced by association with bottom sediments than position in the food chain in aquatic organisms (Wren et al. 1983). The results of the present study are consistent with the literature in that redear sunfish—the species most strongly associated with the bottom—collected from stormwater ponds had the highest mean concentration of Cu (followed by largemouth bass, then bluegill sunfish). Giesy and Wiener (1977) reported no apparent biomagnification of Cu, a concept that also is consistent with the results obtained in the present study.

The Canadian Food and Drug Directorate has set a tolerance of 100 mg/kg for Cu (Uthe and Bligh 1971). The fish collected in the present study had mean concentrations below this value.

According to Moore and Ramamoorthy (1984), the toxic level of Cu in whole fish has not been determined; however, Cu concentrations in muscle tissue seldom exceed 0.001 mg/kg. The mean concentrations of Cu in fish collected in the present study exceeded this level, but most of the Cu could be located in the liver. Schroeder (1956) indicated that the excess Cu may be stored in fish livers.

No significant correlation was observed between the mean Cu concentration and the length or weight of any of the three fish species examined. This lack of a correlation was consistent with results obtained in many similar studies (Giesy and Wiener 1977; Vinikour et al. 1980; Wren et al. 1983). Wiener and Giesy (1979) found a negative correlation between the concentration and the fish length, evidence of homeostatic regulation of Cu. They listed Cu as an essential trace metal; fish homeostatically control the levels. Bowen (1966) also suggested that because Cu is an essential trace element, its concentration may be under physiological control.

LEAD

Lead is a nonessential, toxic metal (Davies et al. 1976); Pb is present in all tissues and organs of mammals (Forstner and Wittmann 1981). Lead has long been known to cause poisoning in humans (Phillips and Russo 1978). Some historians have attributed the decline of the Roman Empire to the practice of storing wine in lead-glazed pots.

Lead is toxic to aquatic organisms, and fish are the most sensitive (Mathis and Cummings 1973). The kidney, gill, and liver tissues of fish tend to accumulate the highest levels of Pb during aqueous or dietary exposures (Sorensen 1991). Uptake is dependent upon exposure time, aqueous concentration, pH, temperature, salinity, diet, and other parameters, such as the inherent ionoregulatory capacity, osmoregulatory capacity, and metabolism of the species under consideration. Loading of aquatic habitats with Pb can result in complex alterations of teleost trophic levels that can last for centuries (Sorensen 1991). Lead does not accumulate in fish except in cases of extreme pollution (Moore and Ramamoorthy 1984), and uptake typically increases with increasing exposure concentration in water (Eaton 1974; Hodson et al. 1978).

The maximum daily "safe" level of Pb as determined by the World Health Organization is 0.45 mg/kg (Sorensen 1991). The FDA standard for Pb in seafood is 0.5 mg/kg (Suffern et al. 1981). The mean concentrations of all three species examined in the present study exceeded both of these values.

In the United Kingdom, the maximum permitted Pb content in food, with certain exceptions, is 2 mg/kg (Waldron 1980). The joint committee on Food Additives (Food Additives Organization and World Health Organization) has suggested that the tolerable weekly intake of Pb in food and drinks is 3.0 mg/kg per person and the maximum allowable concentration in fish filets is

2.0 mg/kg (Brown et al. 1984). Redear sunfish and largemouth bass in the present study had mean Pb concentrations that exceeded these values. The Canadian Food and Drug Directorate has set tolerances for Pb at 10 mg/kg (Uthe and Bligh 1971). Redear sunfish and largemouth bass collected from the stormwater ponds had mean concentrations that exceeded even this value.

The mean Pb concentrations of redear sunfish, largemouth bass, and bluegill sunfish collected in the present study were compared to values reported in similar studies (Table 18). The mean Pb concentrations of redear sunfish and largemouth bass collected from the stormwater ponds and control sites were higher than values reported in similar studies. This finding suggests that the "background" Pb levels in fish collected from the control sites were as high as, or higher than, contaminated sites in other parts of the United States. Redear sunfish and largemouth bass collected from the stormwater ponds had concentrations that were much higher than other reported values. Bluegill sunfish collected from the stormwater ponds and control sites had mean Pb concentrations that were within the range of values obtained in similar studies.

Many studies have shown that whole fish levels of Pb are higher in fish exposed to contaminated sediments than in controls (Sorensen 1991), a finding that is consistent with the results of the present study. All three study species had higher mean Pb concentrations in stormwater sites than in control sites (Table 14). The difference was statistically significant in the redear sunfish ($p<0.005$), and the difference was almost significant in the largemouth bass ($p=0.0076$). Bluegill sunfish collected from the stormwater ponds also contained more Pb than those from the control sites, and although the difference was not statistically significant, the difference may be biologically important. McIntosh and Bishop (1976) found that bluegill sunfish had a mean Pb concentration that was significantly higher than the metal concentrations of similar species from lakes and ponds with no known metal inputs, a finding that is similar to the results obtained in the present study.

Table 18. Mean whole body concentrations of lead (mg/kg wet weight) in various fish species collected in various studies

Location	Species	Lead Concentration	Reference
Stormwater ponds, Orlando, Florida	Redear sunfish	15.78	This study
Control sites, Orlando, Florida	Redear sunfish	5.27	This study
Pickwick Reservoir, Alabama	Redear sunfish	3.40	Dycus 1986
Stormwater ponds, Orlando, Florida	Largemouth bass	12.04	This study
Control sites, Orlando, Florida	Largemouth bass	5.77	This study
Pickwick Reservoir, Alabama	Largemouth bass	3.30	Dycus 1986
Wilson Reservoir, Alabama	Largemouth bass	3.50	Dycus 1986
Skinface Pond, South Carolina	Largemouth bass	1.25	Wiener and Giesy 1979
Stormwater ponds, Orlando, Florida	Bluegill sunfish	0.77	This study
Control sites, Orlando, Florida	Bluegill sunfish	0.54	This study
Little Center Lake, Indiana	Bluegill sunfish	1.52	McIntosh and Bishop 1976
Wilson Reservoir, Alabama	Bluegill sunfish	1.39	Dycus 1986
Pickwick Reservoir, Alabama	Bluegill sunfish	2.87	Dycus 1986
Upper Mississippi River	Bluegill sunfish	0.55	Wiener et al. 1982
Skinface Pond, South Carolina	Bluegill sunfish	0.27	Wiener and Giesy 1979
United States	Many species	0.19	Lowe et al. 1985

The results of the present study are consistent with the literature in that no trophic level biomagnification of Pb was observed among fish of different trophic positions (Wiener and Giesy 1979; Wren et al. 1983). The results also were similar to those found with other metals—the redear sunfish collected from the stormwater ponds had the highest mean Pb concentration of all fish sampled. Leland and McNurney (1974) reported higher concentrations of Pb in fish classified as grazers and detritus feeders than in predatory fish, and the redear sunfish is most strongly associated with the bottom. Largemouth bass collected from the stormwater ponds had mean concentrations that were lower than those of the redear sunfish; however, largemouth bass had higher mean concentrations of Pb than the bluegill sunfish collected from the stormwater ponds.

Gasoline combustion accounts for more than 80 percent of Pb in air (Lagerwerff 1972). Anthropogenic burdens of Pb are evident even in remote lakes in undeveloped watersheds, due to long-range atmospheric transport and deposition (Wiener 1987). These atmospheric sources may explain why the composite sediment samples collected from the control sites had a higher mean Pb concentration than samples collected from the stormwater ponds. Because the Pb in the sediment collected from the control sites is of more ancient origin, it may not be as readily available to the fish living there. Atmospheric deposition also may explain why the fish collected from the control sites had higher mean concentrations than those reported in many other studies. Because the fish that live in stormwater ponds receive continuous significant inputs of Pb, the mean concentration of the fish collected from the stormwater ponds was higher than in those from the control sites.

No significant correlation was observed between the mean Pb concentration and the length and weight of any of the three study species. Other researchers have found the same result (Mathis and Kevern 1975; Murphy et al. 1978b; Wiener and Giesy 1979; Vinikour et al. 1980). Usually, individual variation in whole body concentrations of Pb are large; therefore, trends with weight are seldom observed (Vinikour et al. 1980).

ZINC

Zinc is an essential element for human and animal growth. It is a constituent of all cells and an important cofactor for certain enzymes and has a relatively low toxicity to man (Phillips and Russo 1978). In view of the essential nature of Zn and the high Zn concentration in vertebrate tissues, one might speculate that

Zn serves only useful functions in fish (Sorensen 1991). However, at certain concentrations, Zn is known to be toxic to fish; it causes mortality, growth retardation, tissue alterations, respiratory and cardiac changes, inhibition of spawning, and a multitude of additional detrimental effects. Zinc destroys the gill epithelium of freshwater fish and consequently causes tissue hypoxia (Spear 1981). Zinc is readily accumulated by freshwater fish from both food and water, but internal organs and bones accumulate much higher levels than edible muscle tissue (Phillips and Russo 1978).

The mean whole body concentrations of Zn in redear sunfish collected in the present study were compared to values reported in similar studies (Table 19). The mean Zn concentration of redear sunfish collected from the stormwater ponds, although significantly higher ($p<0.005$) than in those from the control sites, was much lower than values reported for redear sunfish from the contaminated West Basin, Palestine Lake, Indiana. The mean Zn concentrations of redear sunfish collected from the control sites were similar to values obtained from another uncontaminated site.

The mean whole body concentrations of Zn in largemouth bass collected in the present study were compared to values reported in similar studies (Table 20). The mean Zn concentration of largemouth bass collected from the stormwater ponds was higher than other reported values. Largemouth bass collected from the control sites had mean concentrations of Zn that were similar to those in largemouth bass collected from an uncontaminated system in Indiana.

The mean Zn concentrations of bluegill sunfish collected in the present study were compared to values reported in similar studies (Table 21). The mean Zn concentration in bluegill sunfish collected from the stormwater ponds and control sites was within the range of reported values.

Table 19. Mean whole body concentrations of zinc (mg/kg wet weight) in redear sunfish, *Lepomis microlophus*, collected in various studies

Location	Zinc Concentration	Reference
Contaminated Systems		
Stormwater ponds, Orlando, Florida	42.42	This study
West Basin, Palestine Lake, Indiana	119.25	Murphy et al. 1978b
Pickwick Reservoir, Alabama	27.37	Dycus 1986
Uncontaminated Systems		
Control sites, Orlando, Florida	24.83	This study
East Basin, Palestine Lake, Indiana	26.50	Murphy et al. 1978b

The Canadian Food and Drug Directorate has established a Zn tolerance of 100 mg/kg (Uthe and Bligh 1971). All fish collected in the present study had mean Zn concentrations below this value.

Seven of the eleven species collected from the contaminated West Basin of Palestine Lake, Indiana, had higher whole body Zn concentrations than those from the uncontaminated East Basin of Palestine Lake. Redear sunfish and bluegill sunfish were two of the seven species. Maximal values averaged 119.25 mg/kg for redear sunfish (Murphy et al. 1978b). Murphy et al. also found that largemouth bass and bluegill sunfish in an ecosystem heavily contaminated by trace metals accumulated significantly more Zn than bass and bluegill sunfish from an uncontaminated ecosystem. These results are consistent with the findings of the present study. All three species collected from stormwater ponds had higher mean Zn concentrations than those from the control

Table 20. Mean whole body concentrations of zinc (mg/kg wet weight) in largemouth bass, *Micropterus salmoides*, collected in various studies

Location	Zinc Concentration	Reference
Contaminated Systems		
Stormwater ponds, Orlando, Florida	29.99	This study
West Basin, Palestine Lake, Indiana	29.75	Murphy et al. 1978b
Wilson Reservoir, Alabama	13.00	Dycus 1986
Pickwick Reservoir, Alabama	12.80	Dycus 1986
Skinface Pond, South Carolina	18.75	Wiener and Giesy 1979
Uncontaminated Systems		
Control sites, Orlando, Florida	21.18	This study
East Basin, Palestine Lake, Indiana	19.75	Murphy et al. 1978b

sites (significantly higher at a $p<0.005$ for redear sunfish and largemouth bass) (Table 14). Other researchers obtained similar results for bluegill sunfish (McIntosh and Bishop 1976).

The results of the present study indicated that no trophic level biomagnification is occurring for Zn, a finding that is consistent with results obtained by Wiener and Giesy (1979). The redear sunfish collected from the stormwater ponds contained the highest mean concentration, followed by bluegill sunfish and then by largemouth bass. These findings were consistent with literature reports and with the results obtained for most of the heavy metals in the present study.

Table 21. Mean whole body concentrations of zinc (mg/kgm wet weight) in bluegill sunfish, *Lepomis macrochirus*, collected in various studies

Location	Zinc Concentration	Reference
Contaminated Systems		
Stormwater ponds, Orlando, Florida	36.61	This study
West Basin, Palestine Lake, Indiana	56.25	Murphy et al. 1978b
Wilson Reservoir, Alabama	31.00	Dycus 1986
Pickwick Reservoir, Alabama	48.00	Dycus 1986
Skinface Pond, South Carolina	35.50	Wiener and Giesy 1979
Little Center Lake, Indiana	45.00	McIntosh and Bishop 1976
Par Pond, South Carolina	43.30	Giesy and Wiener 1977
Uncontaminated Systems		
Control sites, Orlando, Florida	30.72	This study
East Basin, Palestine Lake, Indiana	34.75	Murphy et al. 1978b

One difference was observed when Zn was compared to the other heavy metals. Bluegill sunfish collected from the stormwater ponds had a mean Zn concentration that was higher than that of largemouth bass collected from the stormwater ponds. This finding was consistent with Murphy et al. (1978b), who found that bluegill sunfish contained significantly greater concentrations of Zn than did bass, probably because of differences in feeding behavior.

No significant correlation was observed between the mean Zn concentration and length or weight of any species studied. This agreed with results obtained by Cross et al. (1973).

Other researchers, however, have found a significant negative correlation between total length and Zn concentration (Giesy and Wiener 1977; Wiener and Giesy 1979; Vinikour et al. 1980). Vinikour et al. (1980) suggested that the negative correlation is related to fish creating new tissues at a greater rate than metals are assimilated into the tissues. A steady-state concentration is never reached (dilution by growth). There was a negative, although not significant, correlation (p=0.05) between the mean Zn concentration and the length and weight of the bluegill sunfish collected in the present study. Wren et al. (1983), however, found a significant positive correlation between Zn and the length of northern pike. It is evident that fish under certain conditions can balance internal levels of Zn, despite environmental fluctuations (Goodyear and Boyd 1972; Roch et al. 1982), or that fish can accumulate levels that are altered by the extent of the environmental contamination (Murphy et al. 1978b).

CONCLUSIONS

The results of the present study indicate that Ag, Cd, Ni, Cu, Pb, and Zn, all metals present in stormwater runoff, are bioaccumulating in the fish living in the stormwater ponds. Redear sunfish, a bottom feeder, is bioaccumulating significant concentrations of Ag, Cd, Ni, Cu, Pb, and Zn in the stormwater ponds. Largemouth bass, a predator, is bioaccumulating statistically significant concentrations of Cd and Zn and important concentrations of Ag, Ni, and Pb in these ponds. Although these last three metals do not achieve statistical significance in largemouth bass, the concentrations are judged to be biologically meaningful. The omnivorous bluegill sunfish that lives in the stormwater ponds is bioaccumulating significant concentrations of Cu. The Cd, Ni, Pb, and Zn concentrations found in these bluegill sunfish from the stormwater ponds may represent biologically significant concentrations because the concentrations were higher than concentrations found in bluegill sunfish from the control ponds.

The data suggest that As and Cr are not bioaccumulating in the fish living in stormwater ponds. The amount of As and Cr entering these ponds from stormwater runoff is minimal. The results do suggest, however, that As, Cr, and Pb are bioaccumulating in the fish collected from the control ponds in central Florida, with unknown causes and consequences.

Results indicate that fish living in stormwater ponds bioaccumulate significant concentrations of heavy metals and that there are differences in heavy metal concentrations between species with different foraging strategies.

RECOMMENDATIONS

Even though the stormwater ponds were only 3–5 years old when the fish were collected, significantly elevated levels of six heavy metals were found in the resident fish. Because the results of the present study show that the fish living in stormwater ponds are bioaccumulating significant concentrations of heavy metals, attracting wildlife to these ponds and use as mitigation areas should be discouraged.

Stormwater ponds help keep the lakes and rivers of Florida from becoming polluted from urban runoff; however, the fish that live in these ponds represent a potentially contaminated food source for wildlife. The effect on the wading birds and other wildlife that feed on the fish living in stormwater ponds is unknown and was beyond the scope of the present study. To determine whether stormwater ponds have a detrimental effect as a food source, research is needed to document

- how often predators forage in stormwater ponds,
- the heavy metal concentrations in other faunal components of stormwater ponds (insects, crustaceans, frogs, turtles, etc.), and
- the effects on predators whose food source contains significant heavy metal concentrations.

In addition, causes of higher levels of As and Cr in fish collected from the control sites compared to fish collected from the stormwater ponds should be investigated.

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APPENDIX: LABORATORY RESULTS

Table A1. Heavy metal concentrations (mg/kg wet weight) of redear sunfish collected from stormwater ponds

Fish No.	Arsenic	Cadmium	Chromium	Lead	Silver	Copper	Zinc	Nickel
1	0.0316	1.39	<0.005	17.9	0.697	4.38	27.6	6.77
2	0.0269	1.49	<0.005	19.9	0.870	8.33	47.3	8.46
3	0.0391	1.61	<0.005	24.9	1.17	18.0	97.8	6.30
4	0.00155	1.41	<0.005	22.5	1.31	5.63	50.3	6.76
5	<0.0005	1.15	2.00	12.4	0.764	5.54	31.5	6.59
6	<0.0005	2.41	<0.005	17.0	<0.005	6.80	35.8	9.91
7	<0.0005	2.00	<0.005	26.6	<0.005	7.32	60.6	11.0
8	<0.0005	2.11	<0.005	26.4	0.132	7.52	54.6	8.84
9	0.00762	1.29	<0.005	8.28	0.0920	5.61	35.1	5.25
10	0.00556	1.51	1.01	14.3	0.336	5.63	52.6	5.97
11	<0.0005	4.51	<0.005	5.89	0.131	3.11	31.5	0.432
12	0.0577	1.14	<0.005	12.0	0.381	5.74	41.5	1.66
13	<0.0005	0.872	<0.005	7.56	0.291	4.20	28.7	0.895
14	<0.0005	0.903	<0.005	10.4	0.347	4.89	22.0	0.278
15	<0.0005	0.789	<0.005	10.7	0.338	2.87	19.5	0.694

Table A2. Heavy metal concentrations (mg/kg wet weight) of redear sunfish collected from control sites

Fish No.	Arsenic	Cadmium	Chromium	Lead	Silver	Copper	Zinc	Nickel
1	<0.0005	0.438	0.213	6.09	<0.001	1.17	28.5	0.712
2	<0.0005	0.299	0.400	7.63	<0.001	0.853	25.3	0.549
3	<0.0005	0.245	0.343	6.73	<0.001	0.632	23.2	0.652
4	<0.0005	0.412	0.726	8.32	<0.001	0.941	20.4	0.978
5	0.0131	0.164	0.336	6.48	<0.001	0.898	30.1	0.552
6	0.00500	0.411	0.885	11.8	<0.001	1.27	31.8	1.23
7	<0.0005	0:307	0.765	8.42	<0.001	1.94	30.4	1.29
8	0.00380	0.0794	0.358	3.38	<0.001	1.05	17.7	0.378
9	0.311	<0.001	0.472	3.08	<0.001	0.793	24.3	0.745
10	<0.0005	0.196	0.490	3.69	<0.001	0.662	30.4	0.661
11	0.0133	0.0674	0.253	2.16	<0.001	0.859	21.6	<0.003
12	<0.0005	0.0167	0.0723	0.001	<0.001	0.299	23.9	<0.003
13	0.0542	0.170	0.360	4.96	<0.001	0.631	18.1	0.398
14	0.0220	0.167	0.424	5.45	<0.001	0.460	23.2	0.474
15	<0.008	<0.001	0.461	0.810	<0.001	0.723	23.6	<0.015

Table A3. Heavy metal concentrations (mg/kg wet weight) of largemouth bass collected from stormwater ponds

Fish No.	Arsenic	Cadmium	Chromium	Lead	Silver	Copper	Zinc	Nickel
1	0.0361	1.27	<0.005	19.1	1.15	3.95	21.7	4.59
2	<0.0005	4.52	<0.005	9.39	0.512	1.31	42.6	1.60
3	0.0215	2.51	<0.005	6.88	0.197	1.52	29.5	1.84
4	<0.0005	5.67	<0.005	29.2	<0.005	1.31	24.8	0.545
5	0.00311	3.08	<0.005	14.9	0.220	6.63	32.9	0.677
6	0.00364	1.43	<0.005	18.7	1.10	6.39	30.4	6.61
7	0.0125	1.39	<0.005	17.6	1.13	5.92	26.7	6.04
8	0.00782	1.32	<0.005	8.50	<0.005	6.14	24.8	4.63
9	0.0105	1.09	<0.005	18.1	<0.005	5.17	21.7	5.63
10	<0.0005	2.93	1.11	0.553	1.05	5.38	17.9	1.32
11	0.0357	3.81	<0.005	8.53	0.0656	0.906	32.0	0.820
12	<0.0005	5.46	<0.005	14.0	0.565	5.05	45.9	1.56
13	<0.0005	5.51	<0.005	<0.001	<0.005	4.98	24.2	0.120
14	<0.0005	4.15	0.444	8.89	0.222	1.27	44.5	0.496
15	<0.0005	3.32	<0.005	6.33	0.0638	1.24	30.3	0.389

Table A4. Heavy metal concentrations (mg/kg wet weight) of largemouth bass collected from control sites

Fish No.	Arsenic	Cadmium	Chromium	Lead	Silver	Copper	Zinc	Nickel
1	0.0259	0.558	1.18	12.7	<0.001	2.64	27.2	3.02
2	<0.0005	0.232	0.586	3.54	<0.001	5.61	27.4	1.98
3	0.0134	0.301	0.720	6.87	<0.001	1.72	38.8	1.29
4	0.415	0.269	0.625	7.22	<0.001	1.56	20.3	0.762
5	<0.0005	0.0483	0.783	2.15	<0.001	46.1	9.27	0.270
6	0.494	0.496	0.913	10.3	<0.001	1.09	25.0	1.28
7	<0.0005	0.0475	0.475	1.88	<0.001	2.50	15.2	1.02
8	0.0197	0.302	0.909	7.02	<0.001	0.928	24.1	0.863
9	0.156	0.350	0.837	8.81	<0.001	0.702	24.0	1.14
10	<0.0005	0.279	0.688	6.49	<0.001	1.24	15.6	4.08
11	<0.0005	0.155	0.471	4.98	0.613	1.66	14.8	0.606
12	0.0181	0.231	0.427	5.50	<0.001	0.637	21.2	0.457
13	0.00198	0.237	0.397	5.41	<0.001	0.668	13.8	0.418
14	0.0127	0.115	0.393	3.31	<0.001	0.780	19.1	0.232
15	<0.008	<0.001	0.465	0.391	<0.001	2.89	21.9	0.322

Table A5. Heavy metal concentrations (mg/kg wet weight) of bluegill sunfish collected from stormwater ponds

Fish No.	Arsenic	Cadmium	Chromium	Lead	Silver	Copper	Zinc	Nickel
1	<0.008	0.0484	0.546	0.0260	0.0289	1.18	26.9	0.0880
2	<0.008	<0.001	0.367	0.786	0.0617	1.78	26.9	0.140
3	<0.008	<0.001	0.554	1.01	<0.001	1.32	37.2	0.0868
4	<0.008	<0.001	0.372	0.219	<0.001	0.726	24.3	0.0174
5	<0.008	0.00243	0.397	1.55	0.297	1.51	29.1	0.208
6	<0.008	0.00988	0.438	0.481	<0.001	1.21	28.3	0.0318
7	<0.008	<0.001	0.495	0.295	0.0192	1.90	28.8	0.287
8	<0.008	0.0108	0.615	0.171	<0.001	4.32	36.9	0.543
9	<0.008	<0.001	0.654	0.794	<0.001	2.28	43.4	<0.015
10	<0.008	<0.001	0.654	1.01	<0.001	1.20	59.9	0.0975
11	<0.008	<0.001	0.583	1.70	<0.001	0.984	36.9	<0.015
12	<0.008	<0.001	0.796	0.596	<0.001	2.75	55.7	<0.015
13	<0.008	<0.001	0.385	0.304	<0.001	3.52	39.3	0.115
14	<0.008	<0.001	0.562	1.20	<0.001	4.50	37.6	0.664
15	<0.008	0.00504	0.567	1.37	<0.001	2.09	38.0	<0.015

Table A6. Heavy metal concentrations (mg/kg wet weight) of bluegill sunfish collected from control sites

Fish No.	Arsenic	Cadmium	Chromium	Lead	Silver	Copper	Zinc	Nickel
1	<0.008	0.00489	0.497	1.00	<0.001	0.793	35.0	<0.015
2	<0.008	<0.001	0.544	0.918	0.00708	0.967	32.2	0.0671
3	<0.008	<0.001	0.406	0.040	<0.001	0.879	28.6	0.285
4	<0.008	<0.001	0.549	<0.001	<0.001	0.888	29.5	0.161
5	<0.008	<0.001	0.489	0.727	<0.001	1.18	41.3	<0.015
6	<0.008	0.0321	0.381	0.406	<0.001	2.00	17.6	<0.015
7	<0.008	<0.001	0.454	0.820	<0.001	0.900	18.8	<0.015
8	<0.008	0.00477	0.787	0.403	<0.001	1.33	37.9	<0.015
9	<0.008	<0.001	0.473	<0.001	<0.001	1.07	21.9	<0.015
10	<0.008	<0.001	0.401	0.502	<0.001	1.27	39.6	<0.015
11	<0.008	0.00103	0.410	<0.001	<0.001	1.38	26.7	<0.015
12	<0.008	<0.001	0.454	0.661	<0.001	0.843	33.0	<0.015
13	<0.008	<0.001	0.543	0.357	<0.001	0.954	36.6	<0.015
14	<0.008	<0.001	0.583	1.70	<0.001	0.984	36.9	<0.015
15	<0.008	<0.001	0.371	0.521	<0.001	0.675	25.2	<0.015

Table A7. Heavy metal concentrations (mg/kg wet weight) of composite sediment samples from stormwater ponds

Location	As	Cd	Cr	Pb	Ag	Cu	Zn	Ni
Lake Howell Square	0.0564	0.380	2.08	7.27	0.168	7.26	65.7	11.4
Country Lake Village	0.214	0.475	2.12	3.11	0.326	2.39	24.2	1.62
Jamestown Plaza	14.7	0.0694	2.77	8.31	0.0647	15.8	16.1	0.0497
Briar Creek Apartments	6.12	0.144	1.53	5.18	0.164	37.5	36.9	0.0419
Regatta Shores	<0.008	<0.001	0.744	0.612	<0.001	20.7	11.4	0.336
Lake Way Road	0.177	0.393	2.96	3.15	0.236	8.98	17.3	1.23
University Boulevard	0.191	0.500	3.08	6.72	0.281	6.13	30.2	1.75

Note: As = arsenic
Cd = cadmium
Cr = chromium
Pb = lead
Ag = silver
Cu = copper
Zn = zinc
Ni = nickel

Table A8. Heavy metal concentrations (mg/kg wet weight) of composite sediment samples collected from control sites

Location	As	Cd	Cr	Pb	Ag	Cu	Zn	Ni
E.H. Kilbee Ranch	19.7	0.0476	2.63	7.49	0.604	2.37	12.5	0.0531
Lake at Pickett Downs	95.3	0.118	12.9	28.4	0.0904	6.95	13.8	0.1660
Sand Lake, Wekiwa Springs State Park	1.28	0.137	0.551	3.70	0.450	0.884	4.92	0.0307
Buck Lake	4.22	0.128	1.00	4.12	0.202	1.74	9.80	0.0315

Note: As = arsenic
Cd = cadmium
Cr = chromium
Pb = lead
Ag = silver
Cu = copper
Zn = zinc
Ni = nickel

Table A9. Length and weight of redear sunfish collected from stormwater ponds

Fish No.	Standard Length (cm)	Total Length (cm)	Weight (g)
1	14.0	17.0	110.0
2	13.0	16.0	86.8
3	10.3	12.5	37.7
4	9.5	12.0	37.6
5	7.7	9.4	18.6
6	10.5	13.0	38.3
7	9.8	12.3	27.9
8	7.0	8.5	9.6
9	7.3	8.8	10.5
10	6.5	8.5	9.5
11	9.9	12.4	33.0
12	9.9	12.4	33.2
13	9.3	11.8	26.0
14	8.4	10.5	17.5
15	5.9	7.4	5.9

Table A10. Length and weight of redear sunfish collected from control sites

Fish No.	Standard Length (cm)	Total Length (cm)	Weight (g)
1	11.1	14.2	41.6
2	11.5	14.5	47.7
3	9.0	11.5	21.9
4	10.8	13.1	37.7
5	10.5	13.2	32.9
6	8.9	10.6	17.0
7	11.1	14.0	40.9
8	7.4	9.3	10.8
9	7.5	9.5	11.9
10	7.6	9.1	8.9
11	11.9	15.0	49.1
12	8.9	11.1	17.2
13	10.0	12.2	26.1
14	10.0	12.1	27.1
15	9.8	12.2	26.7

Table A11. Length and weight of largemouth bass collected from stormwater ponds

Fish No.	Standard Length (cm)	Total Length (cm)	Weight (g)
1	15.7	19.2	101.9
2	9.0	11.1	13.5
3	8.8	9.6	7.0
4	8.0	9.5	8.4
5	6.6	7.8	3.8
6	17.5	20.5	105.8
7	19.0	22.3	119.6
8	19.7	23.5	134.1
9	17.5	21.5	110.7
10	21.5	25.8	193.2
11	9.0	10.8	11.1
12	8.3	10.2	7.0
13	7.7	9.1	6.7
14	7.1	8.8	5.2
15	7.4	8.8	5.6

Table A12. Length and weight of largemouth bass collected from control sites

Fish No.	Standard Length (cm)	Total Length (cm)	Weight (g)
1	24.2	28.5	256.6
2	20.7	25.8	193.1
3	14.6	17.6	54.1
4	13.9	17.0	44.8
5	12.0	14.5	31.6
6	16.3	20.0	78.7
7	24.5	30.0	312.7
8	15.0	18.6	59.1
9	12.9	16.1	37.3
10	19.8	24.5	139.6
11	21.5	26.3	168.9
12	10.7	12.3	16.2
13	11.0	13.4	21.1
14	9.6	11.5	12.5
15	25.1	30.3	323.8

Table A13. Length and weight of bluegill sunfish collected from stormwater ponds

Fish No.	Standard Length (cm)	Total Length (cm)	Weight (g)
1	10.5	12.6	39.5
2	10.0	12.1	29.8
3	9.9	11.3	18.8
4	8.7	10.5	16.5
5	10.0	12.3	32.3
6	6.5	7.3	7.8
7	5.9	7.6	7.3
8	5.2	6.4	4.4
9	4.7	6.0	4.0
10	4.6	5.6	3.6
11	8.9	11.4	22.5
12	6.8	9.1	9.7
13	6.5	8.4	9.6
14	7.3	9.6	9.7
15	6.7	9.0	9.4

Table A14. Length and weight of bluegill sunfish collected from control sites

Fish No.	Standard Length (cm)	Total Length (cm)	Weight (g)
1	11.5	15.0	51.6
2	9.9	12.4	30.7
3	7.3	9.2	14.7
4	11.5	14.6	50.5
5	8.3	10.5	17.9
6	16.1	20.6	154.7
7	15.0	19.2	130.1
8	12.4	15.6	55.0
9	14.6	19.0	97.1
10	11.4	14.5	40.4
11	12.9	16.6	81.9
12	10.8	14.0	43.3
13	10.4	13.5	38.7
14	7.9	10.1	14.9
15	11.4	14.2	45.0