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Skeletal Deformities in Smallmouth Bass, *Micropterus dolomieui*, from Southern Appalachian Reservoirs

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Abstract. Smallmouth bass (*Micropterus dolomieui*) populations in two of five reservoirs sampled in the southern Appalachian Mountains contained high percentages of individuals with lordosis, kyphosis, or scoliosis. Deformities of the vertebral column occurred in several year classes and varied with fish size; they were absent in small fish, present in 25–30% of the fish 241–300 mm long, and then decreased in occurrence with increased length. Because environmental contamination is often responsible for high occurrences of deformed fish, whole-body concentrations of contaminants, bone development characteristics, and blood plasma concentrations of calcium and phosphorus in normal and deformed fish were measured and compared the results with those for fish from reservoirs where no deformities were found. Vertebrae were significantly weaker and more elastic in deformed than in normal fish, but biochemical properties of vertebrae were similar among the groups tested. Concentrations of pesticides and metals were not elevated in deformed fish, and concentrations of calcium and phosphorus in blood plasma were similar in normal and deformed groups. Most environmental contaminants that have been shown to cause fish deformities could be discounted as causative agents on the basis of these results; however, the exact cause was not determined. Further attempts to diagnose the cause of the deformities were limited by the lack of background information on relationships among bone development processes, types of stresses that cause deformities, and types of bone tissue in fish.

A high incidence of spinal deformities in smallmouth bass, *Micropterus dolomieui,* from Chatuge Reservoir, Georgia-North Carolina, was first noted in 1978 when anglers began reporting frequent catches of adult bass with severe spinal deformities (lordosis, kyphosis, and scoliosis). Although deformed fish are occasionally found in many wild populations, high incidences often reflect environmental problems—especially contamination from inorganic and organic pollutants (Bengtsson 1975). In fact, it has been proposed that deformities are useful indicators of surface-water contamination (Bengtsson 1979; Mehrle *et al.* 1982).

The potential for environmental contamination prompted us to evaluate smallmouth bass populations in Chatuge Reservoir and other nearby impoundments to determine the incidence and types of deformities and to investigate possible causes. The incidence of deformed smallmouth bass was 20–30% of the adults collected in both Fontana Reservoir, North Carolina, and Chatuge Reservoir. Because of the potential environmental significance of the deformity problem, studies were conducted to describe the deformities and evaluate possible causes by measuring bone development character-

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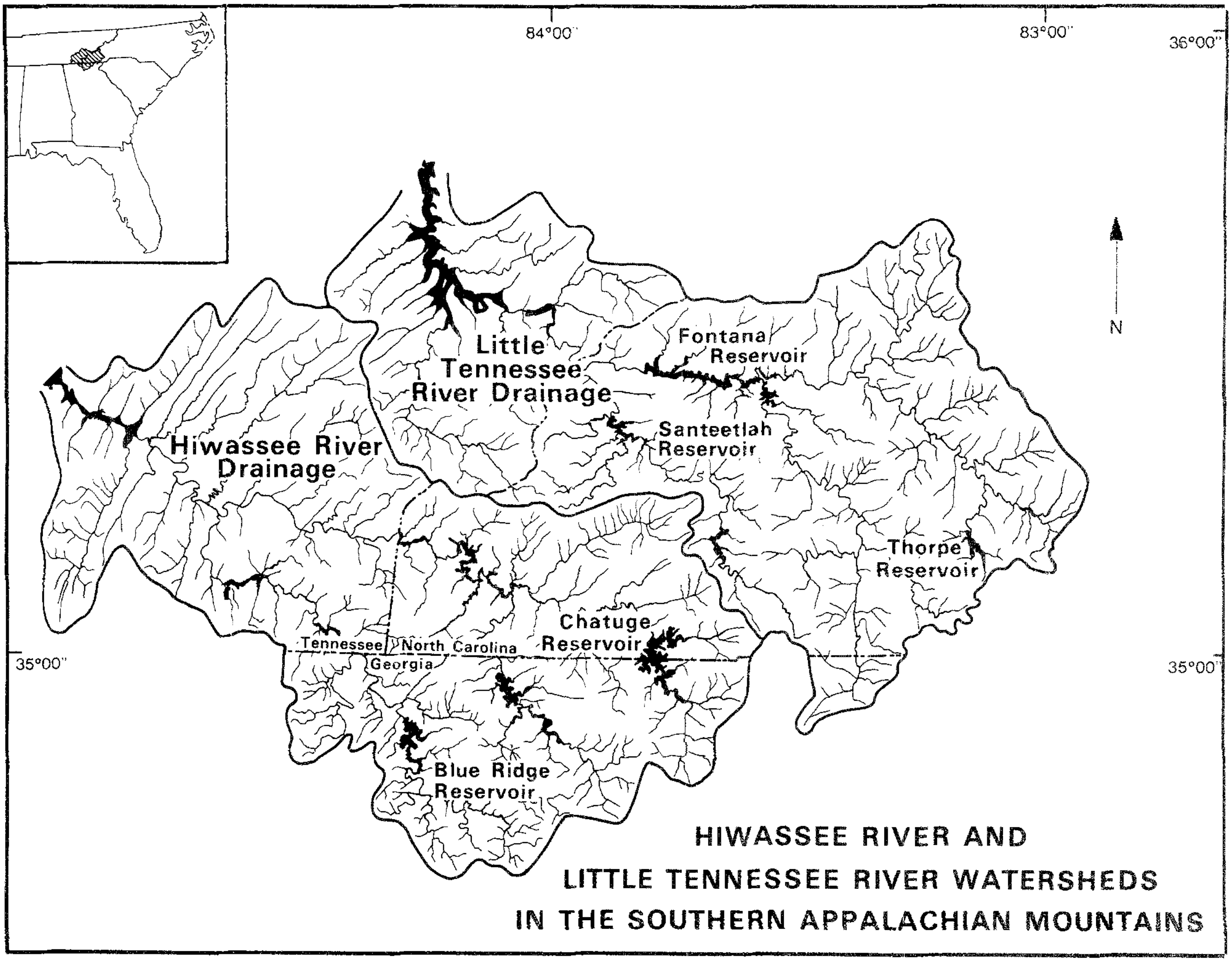

Fig. 1. Locations of reservoirs in the southern Appalachian Mountains

istics, plasma calcium and phosphorus concentrations, and concentrations of contaminants in fish tissues.

Methods

Study Area

The reservoirs sampled are part of the Tennessee Valley Authority network of flood control and hydroelectric impoundments constructed during the 1940's and 1950's in the Southern Blue Ridge Province of the Appalachian Mountain range (Figure 1). Watersheds are primarily forested and lack extensive agricultural or industrial development. The surrounding area is mountainous (elevations of 400–2300 m above mean sea level), and about 45% of the land is in national forests and parks managed by the U.S. Government. About 9% of this region is used for agriculture, and 2% is urban. Impoundments in this region typically are large and deep, undergo temperature stratification in the summer, and have relatively long hydraulic residence times.

The two impoundments with deformed smallmouth bass—Chatuge and Fontana Reservoirs—occur in separate sub-basins of the Tennessee Valley (Figure 1). Chatuge Reservoir (2850 ha surface area) is the uppermost impoundment of the Hiwassee River, and Fontana Reservoir (4300 ha) is on the Little Tennessee River. Samples were also collected at Blue Ridge Reservoir (1320 ha, Hiwassee River sub-basin) and Thorpe and Santeetlah Reservoirs (585 and 1145 ha, Little Tennessee River sub-basin), but no deformed smallmouth bass were found. Fish assemblages in these five reservoirs are relatively diverse, but high incidences of deformities have not been reported for species other than smallmouth bass in Chatuge and Fontana Reservoirs.

Fish Collections

A sample of 733 smallmouth bass was collected throughout Chatuge Reservoir by electrofishing and applying rotenone to coves ("cove rotenoning") during 1981–1983. Fish were measured (mm total length), scales were removed from subsamples for aging, and the fish were preserved either by freezing at −30°C or fixation in 10% neutral buffered formalin. Skeletal condition was determined by x-ray analysis. The Georgia Department of Natural Resources provided data for 747 smallmouth bass caught by anglers and visually examined by Department personnel in 1982 and 1983. All fish were separated into six groups based on total length (mm): ≦180, 181–240, 241–300, 301–360, 361–420, and ≧421.

Samples from other reservoirs were collected by cove rotenoning (Thorpe) or electrofishing (Blue Ridge, Fontana, Santeetlah) during summer or fall 1983. Sampling efforts were distributed throughout each reservoir; fish were processed as described for the Chatuge Reservoir samples.

Bone Development Characteristics

All fish used in bone development analyses were preserved by freezing. Analyses of mechanical properties, density, and biochemical composition of bone were conducted on samples of 13 normal and 11 deformed bass from Chatuge Reservoir. For comparison, nine normal smallmouth bass were collected from Center Hill Reservoir, Tennessee, in 1982. This impoundment is outside the area of concern and is not known to have a high incidence of deformities in the smallmouth bass population. All fish analyzed were 180–240 mm long and 1 year old; sex ratios were about 1:1 in each sample.

For determination of vertebral mechanical properties, the second to ninth vertebrae were dissected from each fish, cleaned of tissue, and measured (length and diameter, in mm). Compression loading was performed with an Instron testing machine (Model 1132) having a crosshead speed of 5 mm/minute, and vertebral strength (rupture and elastic limit), elasticity (strain and modulus of elasticity), and energy-absorbing capacity (toughness) were determined (Hamilton *et al.* 1981).

After testing mechanical properties, the biochemical composition and density of vertebrae were determined as described by Mayer *et al.* (1977) and Mehrle *et al.* (1982). Vertebrae were dried to a constant weight at 100°C for 2 hr and then split into two fractions and weighed. One fraction (two vertebrae) was used for calcium and phosphorus analysis, and the second (six vertebrae) was used for collagen determinations.

Contaminant Residue Analysis

Two sets of contaminant analyses were performed. First, samples of normal and deformed bass from Chatuge Reservoir and normal bass from Center Hill Reservoir were analyzed for a variety of organic contaminants and metals. Sizes and ages of fish used were similar to those used in the bone analyses. Frozen fish were homogenized and analyzed individually for DDT and derivatives, PCBs, toxaphene, aldrin, dieldrin, lindane, chlordane, mirex, aluminum, arsenic, cadmium, copper, lead, manganese, mercury, and zinc. Analytical and quality control procedures were similar to those reported by Ribick *et al.* (1981) and May and McKinney (1981).

A second set of analyses was conducted for several metals that had previously been reported to cause fish deformities. Cadmium, copper, lead, and zinc were measured in liver, bone, and carcass (excluding the gut, gonads, liver, and backbone) in samples of deformed and normal bass from Chatuge and Fontana Reservoirs and normal bass from Blue Ridge and Santeetlah Reservoirs. Each sample included seven fish that were 181–240 mm long and 1 year old. Concentrations were measured by atomic absorption spectrophotometry (Lowe *et al.* 1985); details of analytical procedures were reported by Garvick (1986).

Plasma Calcium and Phosphorus

Additional smallmouth bass, similar in age and size to those used for bone development and contaminant analyses, were collected from Chatuge, Fontana, Blue Ridge, and Santeetlah Reservoirs to determine plasma calcium and phosphorus concentrations. Plasma mineral determinations can be useful indicators of disrupted osmoregulation and metabolic processes that affect bone mineralization. After capture, fish were anesthetized, blood samples were taken from the caudal vein with heparinized syringes, and plasma was separated by centrifugation. Inorganic phosphate and total plasma calcium were measured spectrophotometrically (Dryer *et al.* 1957; Sarkar and Chauham 1967).

Results

Spinal deformities observed in radiographs of smallmouth bass from Chatuge Reservoir included lordosis, kyphosis, and scoliosis (Figure 2). Many of the larger (≧181 mm) deformed fish showed all three abnormalities. Nearly all deformities appeared as misalignment of the vertebrae. Fused (compressed) and misshapen (hemicentric) vertebrae were commonly found, whereas fractures or other evidence of traumatic injury were rare. In small fish (<181 mm), deformities were more subtle and appeared as slight vertical or lateral curvatures of the spine. Deformities in small fish usually were detectable only from radiographs whereas those in most larger fish were externally obvious.

Incidence of Deformed Fish

Evaluations of fish collected by electrofishing and cove rotenoning in Chatuge Reservoir in 1981–1983 indicated that deformities were not restricted to specific year-classes and that the incidence varied with fish size (Table 1). Only 1.4% of specimens <181 mm long were deformed whereas 20–30% of the larger size groups were affected. Personnel of the Georgia Department of Natural Resources who examined 747 smallmouth bass caught by anglers from Chatuge Reservoir in 1982–1983 detected no deformities in specimens <181 mm but reported deformed backbones in 1–28% of the fish in larger size groups (Table 2). Data from both sources thus indicated that deformities were lacking or not apparent in small fish, increased in occurrence until the fish reached 241–300 mm, and then decreased

Fig. 2. Radiographs of normal (top) and deformed (bottom) smallmouth bass from the Chatuge Reservoir. Fused (solid arrow) and misshapen or hemicentric vertebrae (open arrow) are apparent in the deformed fish

Table 1. Percent incidence of spinal deformities in smallmouth bass collected by rotenone sampling and electrofishing in Chatuge Reservoir, 1981–83, as shown by x-ray analysis. Numbers of fish examined are shown in parentheses

Total length (mm)	1981 Summer and fall	1982 Spring	1982 Summer	1982 Fall	1983 Fall	Years and seasons combined
41–180	4.6	0.6	0.0	5.3	0.6	1.4
	(65)	(173)	(102)	(57)	(162)	(559)
181–240	42.9	7.1	31.2	50.0	20.9	22.1
	(7)	(42)	(16)	(14)	(43)	(122)
241–300	—	25.0	75.0	0.0	30.0	30.0
	(0)	(12)	(4)	(4)	(10)	(30)
301–360	0.0	0.0	0.0	50.0	0.0	20.0
	(1)	(1)	(6)	(6)	(1)	(15)
361–420	—	0.0	50.0	—	—	28.6
	(0)	(3)	(4)	(0)	(0)	(7)

in occurrence with increased length. Since this pattern prevailed for at least 2 years, it is apparent that deformities occurred in more than one year class of fish. Scale samples of smallmouth bass from Chatuge Reservoir showed that lengths of 181–240 mm were usually attained during the second growing season and that growth averaged about 50–60 mm per year thereafter. Sex ratios of Age 1 and older fish were similar in subsamples of normal and deformed fish, suggesting that the occurrence of deformities was not affected by sex.

The sampling of four additional southern Appala-

Table 2. Percent incidence of spinal deformities in smallmouth bass visually examined by creel survey personnel of Georgia Department of Natural Resources at Chatuge Reservoir, 1982–83. Numbers of fish examined are shown in parentheses

Total length (mm)	1982 Spring	1982 Summer	1982 Fall	1983 Spring	1983 Summer	1983 Fall	Years and seasons combined
180	0.0	—	—	—	—	—	0.0
	(1)	(0)	(0)	(0)	(0)	(0)	(1)
181–240	0.0	0.0	0.0	0.0	0.0	33.3	7.1
	(1)	(3)	(3)	(1)	(3)	(3)	(14)
241–300	26.1	14.3	31.2	11.8	40.0	30.0	27.6
	(23)	(7)	(16)	(17)	(20)	(40)	(123)
301–360	16.3	26.7	26.9	11.8	7.0	8.9	13.2
	(43)	(15)	(26)	(85)	(34)	(101)	(304)
361–420	7.8	27.3	21.4	2.3	15.8	3.6	8.9
	(51)	(11)	(14)	(43)	(38)	(56)	(213)
≥421	0.0	0.0	11.1	0.0	0.0	0.0	1.1
	(19)	(9)	(9)	(20)	(14)	(21)	(92)

Table 3. Percent incidence of spinal deformities in smallmouth bass from selected southern Appalachian reservoirs in 1983. Numbers of fish examined are shown in parentheses

Total length (mm)	Reservoir: Blue Ridge	Santeetlah	Fontana	Thorpe
180	0.0	0.0	0.0	0.0
	(25)	(65)	(25)	(306)
181–240	0.0	0.0	29.9	0.0
	(28)	(26)	(77)	(4)
241–300	0.0	0.0	24.6	—
	(18)	(6)	(57)	(0)
301–360	0.0	0.0	0.0	0.0
	(4)	(4)	(7)	(1)
361–420	0.0	—	—	—
	(1)	(0)	(0)	(0)

chian impoundments in 1983 revealed many deformed smallmouth bass in Fontana Reservoir but none in Blue Ridge Reservoir, Georgia, which is in the same drainage sub-basin as Chatuge Reservoir (Hiwassee River) nor in Santeetlah and Thorpe Reservoirs, North Carolina, which are in the same drainage as Fontana Reservoir (Little Tennessee River). In Fontana Reservoir, deformities were not detected in fish <181 mm but occurred in 26% of the large bass (Table 3). The percentages and types of deformities in Fontana Reservoir were virtually identical to those observed in Chatuge Reservoir, suggesting similar or identical causative factors.

Bone Properties

Biochemical properties of vertebrae were similar in deformed and normal smallmouth bass from Chatuge Reservoir and normal fish from Center Hill Reservoir (Table 4). However, all bone mechanical properties except toughness differed significantly among groups (ANOVA, $P \leqq 0.05$). Rupture (force at which vertebrae are fractured) and the elastic limit (force at which permanent damage occurs in vertebrae) were significantly lower in deformed fish than in normal fish from either Chatuge or Center Hill Reservoirs (Table 4). Average values of rupture and elastic limit indicated that vertebrae of deformed fish were about 20% weaker than in normal fish. Moreover, the vertebrae in deformed Chatuge fish were more elastic than those of normal fish. Strain (the amount of deformation incurred by vertebrae just prior to fracture) was increased about 20%, and the modulus of elasticity (an index of stiffness) was decreased about 30%. All characteristics of normal Chatuge bass were similar to those of the Center Hill fish.

Contaminant Residues

The only organic contaminants present at detectable concentrations in fish were α-chlordane and *p,p′*-DDE, which occurred at similar concentrations in all bass from Chatuge and Center Hill Reservoirs. Concentrations of α-chlordane ranged from 0.009 to 0.012 μg/g in normal Chatuge Reservoir fish, 0.007 to 0.040 μg/g in deformed Chatuge Reservoir fish, and 0.005 to 0.010 μg/g in Center Hill Reservoir fish.

Average concentrations for seven of the eight metals tested were not significantly different between Chatuge and Center Hill fish (Table 5); however, zinc was significantly higher in deformed

Table 4. Mean and standard deviation of vertebral characteristics of smallmouth bass from Chatuge and Center Hill Reservoirs

Characteristic	Chatuge Reservoir Normal (N = 13)	Chatuge Reservoir Deformed (N = 11)	Center Hill Reservoir (N = 9)
Biochemical composition			
Collagen (mg/g bone)	221 ± 12	225 ± 17	216 ± 9
Calcium (mg/g bone)	228 ± 12	232 ± 19	233 ± 17
Phosphorus (mg/g bone)	107 ± 5	113 ± 8	113 ± 11
Calcium/phosphorus ratio	2.1 ± 0.1	2.1 ± 0.0	2.1 ± 0.2
Ca + P/Collagen	1.5 ± 0.1	1.5 ± 0.1	1.6 ± 0.1
Density (mg/cm³)	472 ± 39	472 ± 35	500 ± 41
Mechanical properties			
Rupture (g-force/mm²)	959 ± 101	784 ± 150*	988 ± 80
Elastic limit (g-force/mm²)	712 ± 64	564 ± 149*	771 ± 64
Percent strain	9.5 ± 1.2	11.5 ± 2.6*	9.9 ± 1.1
Modulus of elasticity (kg-force/mm²)	14.0 ± 2.1	9.8 ± 2.6*	13.2 ± 1.3
Toughness (g-mm/mm³)	54 ± 9	53 ± 17	58 ± 11
Fish size			
Length (mm)	224 ± 15	222 ± 24	213 ± 17
Weight (g)	120 ± 23	141 ± 48	115 ± 35

* Deformed Chatuge Reservoir fish differed significantly (P ≦ 0.05) from normal Chatuge and Center Hill Reservoir fish

Table 5. Average (± standard deviation) trace metal concentrations (μg/g wet weight) in carcasses of smallmouth bass from Chatuge and Center Hill Reservoirs (n = 5 or 6 per group). Zinc varied significantly (P ≦ 0.05) among groups; values followed by the same letter were not significantly different

Reservoir	Trace metal: Aluminum	Arsenic[a]	Cadmium[a]	Copper	Lead[a]	Mercury[a]	Manganese	Zinc
Chatuge (deformed)	3.4 ± 3.0	<0.05	<0.05	0.52 ± 0.22	<0.05	<0.10	1.60 ± 0.37	23.1 ± 4.7b
Chatuge (normal)	2.6 ± 1.4	<0.05	<0.05	0.36 ± 0.19	0.08 ± 0.05	<0.10	0.92 ± 0.29	17.6 ± 0.8a
Center Hill	1.4 ± 0.4	0.18 ± 0.10	<0.05	0.53 ± 0.16	<0.05	<0.10	0.99 ± 0.33	17.8 ± 2.1a

[a] Average values preceded by a < symbol indicate that concentrations in most fish were less than the analytical detection limits

Chatuge bass (ANOVA, P ≦ 0.05). Concentrations of arsenic, cadmium, lead, and mercury were below analytical detection limits in about 90% of the fish evaluated.

Further evaluations of lead, cadmium, copper, and zinc concentrations in specific smallmouth bass tissues showed no consistent variation between normal and deformed fish or among the four reservoirs (Table 6). Lead concentrations typically were less than analytical detection limits in all tissues; this also occurred for cadmium in carcass and bone and for copper in bone. In the three cases where average concentrations differed significantly among groups, residues tended to be highest in tissues of fish from Blue Ridge Reservoir (e.g., cadmium and copper in liver), where no deformed fish were collected, and lowest in Fontana Reservoir (zinc in liver), where deformed fish were taken. The previously measured high concentrations of zinc in carcass samples of deformed Chatuge bass (Table 5) were not duplicated in these analyses (Table 6).

Concentrations of calcium and phosphorus in plasma varied significantly (ANOVA, P ≦ 0.05) among reservoirs but showed no apparent relation to the occurrence of deformed fish (Table 7). The only statistical difference observed among locations for plasma calcium was the significantly higher concentration in Blue Ridge fish than in fish from the other reservoirs. Phosphorus concentrations were significantly higher in Fontana Reservoir (normal and deformed) than in Chatuge Reservoir (normal), but were similar to the other groups.

Table 6. Average metal concentrations (μg/g wet weight; ± standard deviation; n = 7) in carcass, liver, and bone of normal and deformed smallmouth bass from four southern Appalachian reservoirs. Cadmium, copper, and zinc in the liver varied significantly ($P \leqq 0.05$) among groups; for these metals, values followed by the same letter were not significantly different

	Cadmium	Copper		Zinc		
Reservoir	Liver	Carcass	Liver	Carcass	Liver	Bone
Blue Ridge	0.15 ± 0.04b	0.48 ± 0.07	2.00 ± 0.25c	18.7 ± 3.1	22.4 ± 2.3b	56.5 ± 8.6
Chatuge (normal)	0.07 ± 0.03a	0.43 ± 0.05	1.88 ± 0.32bc	18.7 ± 2.9	21.8 ± 3.9b	51.6 ± 6.0
Chatuge (deformed)	0.08 ± 0.03a	0.44 ± 0.04	1.97 ± 0.32bc	19.9 ± 2.3	21.6 ± 3.1b	48.9 ± 8.9
Santeetlah	0.09 ± 0.04a	0.54 ± 0.15	1.60 ± 0.55ab	18.7 ± 1.2	22.4 ± 3.9b	50.4 ± 4.9
Fontana (normal)	0.05 ± 0.02a	0.69 ± 0.17	1.29 ± 0.28a	17.0 ± 4.2	17.5 ± 2.7a	54.1 ± 15.6
Fontana (deformed)	0.06 ± 0.02a	0.50 ± 0.11	1.49 ± 0.30a	18.8 ± 2.6	21.3 ± 2.3b	49.0 ± 5.3

Table 7. Average plasma concentrations (± standard deviation; numbers of fish in parentheses) of calcium and phosphorus in normal and deformed smallmouth bass from four southern Appalachian reservoirs. Both minerals varied significantly among groups ($P \leqq 0.05$); values followed by the same letter were not significantly different

	Plasma concentrations (mg/dl)	
Reservoir	Calcium	Phosphorus
Blue Ridge	12.9 ± 3.5b (18)	10.2 ± 1.2ab (8)
Chatuge (normal)	11.3 ± 1.7a (40)	9.1 ± 1.4a (13)
Chatuge (deformed)	11.2 ± 1.2a (4)	11.2ab (1)
Santeetlah	11.3 ± 2.3a (12)	13.1 ± 3.7ab (7)
Fontana (normal)	10.1 ± 2.3a (16)	14.6 ± 2.5b (14)
Fontana (deformed)	11.7 ± 3.7a (5)	15.3 ± 3.0b (5)

Discussion

Heredity and many environmental factors have previously been shown to cause spinal deformities in wild fish populations, making detection of causal relationships difficult. It is generally accepted that skeletal deformities can be environmentally induced in two ways: (1) by alteration of biological processes necessary for maintaining the biochemical integrity of bone, or (2) neuromuscular effects, which lead to deformities without a chemical change in vertebral composition. Our assessment of factors that may be causing the high incidence of deformities in smallmouth bass populations was based on comparisons of available evidence from radiographs, bone development properties, plasma calcium and phosphorus, and contaminant residues, with published information on relationships between environmental variables and fish deformities.

Heredity, temperature extremes, and low dissolved oxygen are unlikely causes of the deformities in smallmouth bass based on electrophoretic evaluation (D. Phillipp, Illinois Natural History Survey, personal communication) and recent water quality data (obtained from the United States Environmental Protection Agency's STORET system). Skeletal deformities caused by electrofishing or electric weirs (Hauck 1949; DeVore and Eaton 1983; Hudy 1985) differ greatly from the deformities we observed. The only reported case of radiation-induced skeletal deformities in a wild population occurred in water contaminated by high concentrations of radioactive wastes (Blaylock 1969). There are no known sources of such wastes in Chatuge or Fontana Reservoirs. Although acid precipitation has been suggested as a potential cause of skeletal deformities in fish (Beamish *et al.* 1975), the similarities of calcium concentrations in vertebrae and blood plasma of deformed and normal fish from Chatuge and Center Hill Reservoirs suggest that stress from exposure to acidic conditions was not responsible for the deformities.

Numerous pesticides, including organochlorines, polychlorinated biphenyls, and fluorinated herbicides can cause skeletal deformities in fish. These compounds typically cause fractures (Mehrle and Mayer 1975; Stehlik and Merriner 1983) or thickened vertebrae (Couch *et al.* 1979), which differ from the compressed and misshapen vertebrae of the smallmouth bass observed in our study. Low or undetectable concentrations of organic contaminants in Chatuge Reservoir bass also suggest that pesticides were not responsible for the deformities. Many organic contaminants alter bone metabolism and affect biochemical composition of vertebrae (Mauck *et al.* 1978; Mehrle *et al.* 1981), but this was not detected in our study. The only organic compounds present at detectable concentrations in Chatuge Reservoir bass, chlordane and *p,p'*-DDE, were also found at similar concentrations in fish from Center Hill Reservoir, and neither has been shown to cause fish deformities. The concentrations we measured are similar to those in many locations (Lowe *et al.* 1985) where no high incidences of deformed fish have been reported.

Organophosphate pesticides, which degrade rapidly in the environment and typically are not identified in residue analyses because they are rapidly metabolized, may also cause fish deformities. Baumann and Hamilton (1984) hypothesized that vertebral abnormalities in white crappies from an Illinois lake were caused by organophosphate insecticides used for agriculture in the watershed. They reported that neither biochemical nor mechanical properties of the fish vertebrae were different between normal and deformed fish. In our study, however, mechanical properties of vertebrae were altered in the deformed fish, suggesting a causative agent different from that identified by Baumann and Hamilton.

Metals cause skeletal deformities in fish by altering bone metabolism, producing biochemical and structural changes in the vertebrae, and by neuromuscular pathways, which can lead to structural alteration of vertebrae without altering bone chemical composition. Cadmium and zinc can affect bone biochemical composition by interfering with mineralization (Muramoto 1981; Sauer and Watanabe 1984) and can also affect neuromuscular activity (Bengtsson 1974; Bengtsson *et al.* 1975). Mercury and lead primarily affect the neuromuscular system (McKim *et al.* 1976; Davies *et al.* 1976). None of the metals previously shown to cause fish deformities seem to be responsible for the smallmouth bass problem. The absence of biochemical differences in vertebrae of deformed and normal fish tends to eliminate metals that affect bone metabolism, such as mercury, lead, cadmium, and zinc. The lack of differences in plasma calcium and phosphorus between normal and deformed fish provides further support for this argument (Roch and Maly 1979; Larsson *et al.* 1981).

Although cadmium and zinc also affect neuromuscular systems, and could perhaps cause bone lesions like those observed, residual concentrations were no higher in fish from populations having deformities than in fish from the other lakes. In fact, the residues of the metals that differed significantly among reservoirs tended to be highest in Blue Ridge Reservoir, where no deformities occurred. Concentrations we measured for metals were within or below concentrations typical of fish collected throughout the United States (Lowe *et al.* 1985). Recent measurements of metal concentrations in the reservoirs we sampled showed no unusually high levels (H. Olem, Tennessee Valley Authority, Chattanooga, Tennessee, personal communication).

In summary, we were not able to determine the exact source of the deformities in smallmouth bass, but the evaluations indicate that environmental contaminants as well as most other factors reported to cause deformities in wild fish populations can be discounted as causative agents. This apparently is an exception to suggestions by Bengtsson (1975, 1979) and Mehrle *et al.* (1982) that occurrences of fish deformities could be used as an index of water contamination; however, it is possible that the deformities observed in smallmouth bass were caused by a contaminant that was neither previously reported to cause deformities nor detectable from our methods.

The existence of differences in vertebral mechanical properties between deformed Chatuge fish and normal fish from Chatuge and Center Hill Reservoirs provided no direct evidence of causative agents. The weakened, more elastic vertebrae in deformed fish are possibly a result of relative long-term degenerative processes that parallel neuromuscular responses to the causative agent. This might explain why there were few signs of deformities in fish shorter than 181 mm. Further diagnosis of the cause of the deformed fish in Chatuge Reservoir by using results of bone mechanical properties is hampered by the lack of published information on bone responses to neuromuscular disorders in fish. Additionally, diagnosis is limited by the lack of information on responses in fish having different bone tissue types. Most studies reported in the literature involve fish with cellular bone, whereas smallmouth bass have acellular bone. There is some indication that these two tissue types respond differently to certain contaminant stresses (Muramoto 1981).

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