Fisheries Session

Selenium-Induced Changes in Fish Populations of a Heated Reservoir

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Abstract: High selenium levels and changes in abundance and size distribution of fishes were discovered after reports of fish dying in Martin Creek Reservoir, Texas. The reservoir functions as a cooling source for a coal-fueled power plant owned by Texas Utilities Generating Co. Analyses of fish muscle tissue by the Texas Department of Health showed selenium concentrations ranging from 2.0 to 9.1 mg/kg. Cove rotenone sampling by the Texas Parks and Wildlife Department indicated biomass of fishes, except common carp, *Cyprinus carpio,* was reduced 72%. Relative biomass of trophic groups was altered with planktivores changing from the largest to the smallest group, carnivores were initially reduced by nearly half, and omnivores more than doubled. Three years after the fish kills, planktivore biomass remained the lowest, carnivores had recovered to approximately 90% of their original biomass, and omnivores continued to dominate the community at 3 times their original abundance.

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Selenium is 1 of several potentially toxic elements that have become more prevalent in aquatic environments during the last decade. The increase in selenium has been caused primarily by burning lignite coal for production of electrical energy. This pollutant is significantly impacting aquatic life in ways that only recently have been fully realized. Toxic concentrations of selenium for fishes have been found to range from 2 to 80 mg/liter (Ellis et al. 1937, Weir and Hine 1970, Niimi and LaHam 1975, Cardwell et al. 1976) and from 0.3 to 42.4 mg/liter for other freshwater animals (Environ. Protection Agency 1980). Toxicity will vary with chemical form of selenium, species, life stage of the organism and duration of exposure. Environmental Protection Agency (1980) criterion for protection of freshwater aquatic life is a maximum concentration of 0.035 mg/liter. This amount is a 24-hour average for inorganic selenite in water with concentration at no time exceeding 0.26 mg/liter.

Toxicity of selenium is due to inability of enzyme systems to distinguish molecular structure of selenium from sulphur. When selenium is substituted for sulphur in cellular constituents, metabolic problems arise due to greater reactivity and lower stability of selenium compounds (Stadtman 1974).

One of the best documented cases of effects of selenium poisoning in an aquatic environment occurred at Belews Lake, North Carolina. Fish populations dramatically declined in number over a 4-year period (1974–1977) and reproduction in all species except common carp, *Cyprinus carpio,* was reduced to near zero (Cumbie 1978, Cumbie and Van Horn 1978). This was attributed to high concentrations of selenium emanating from fly ash sluice water from Belews Creek Steam Station. While the amount of selenium in the water never reached a lethal concentration, it was thought bioaccumulation through the food chain was responsible for elevated levels found in fishes. Sandholm et al. (1973) demonstrated selenium could accumulate in fishes via the food chain. Bioaccumulation has been shown to be directly proportional to the concentration in water and sediment (Fowler and Benayoun 1976) with selenium entering the food chain primarily through phytoplankton. Concentrations in skeletal muscles of those species examined ranged from 5 to 50 mg/kg. Levels in fishes from an unaffected reservoir, Lake Norman, North Carolina, averaged only 0.7 mg/kg.

This paper focuses on fish community changes that occurred after a coal-fueled power plant released selenium-rich water into Martin Creek Reservoir, Texas. This type of situation is likely to be a recurrent problem in power plant reservoirs and it is hoped this study will aid future efforts to document cause and effect.

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Description of Study Area

Martin Creek Reservoir covers 2,000 ha in Rusk County, Texas. The watershed is composed of rolling hills with mixed pine and hardwood forests. The reservoir was constructed in 1974 on Martin Creek, a tributary of the Sabine River, by Texas Utilities Generating Co. as a cooling reservoir for its steam-electric power plant.

Methods

An extensive investigation of a slow die-off of fishes at Martin Creek Reservoir began in July 1979. Possible causes for the die-off were investigated by the Texas Parks and Wildlife Department, Texas Department of Health, and the Texas Department of Water Resources. These included monitoring various physicochemical parameters and testing for heavy metals, metalloids and pesticides in water, sediment, and organic tissues.

Two consultants, Dr. Owen Lind (limnologist, Baylor University) and Dr. Elsie Sorensen (environmental toxicologist, University of Texas) were retained by the Texas Parks and Wildlife Department to provide expertise in various facets of the investigation.

To detect changes in the fish populations, cove rotenone sampling was employed for 3 consecutive years. These collections were conducted each July, 1979 to 1981, in the same areas and by the same personnel and manner as were employed during a previous management survey in July 1977, 1 year prior to initiation of the fish die-off. Three coves, totaling 1.5 ha, were located in different sections of the reservoir within the main waterflow pattern. Nylon block-off nets (16-mm mesh) were used to prevent fish from entering or leaving the sampling area. The nets were installed after sundown (2200–0100 hours) and prior to application of rotenone the following morning. Liquid rotenone (5%) was applied at a rate of 3 mg/liter to ensure a total kill. Fishes were collected for 2 days and separated into species and then into 25-mm size groups. All fish species were counted and weighed by size groups during the first day of collection. During the second day of recovery, fishes were separated by species and size groups and counted; weights were taken only for size groups of species not obtained during the first-day collections. Results were reported as number and kilogram per hectare by size group for each species.

For some comparisons, fishes were grouped by trophic level. These consisted of top carnivores, planktivores, and omnivores (Table 1).

Results and Discussion

A slow die-off of fishes began in Martin Creek Reservoir in July 1978. Two months earlier, the utility company had begun unauthorized discharges from 2 fly-ash ponds into the reservoir. Fly-ash is a by-product of burning coal and often has a high selenium content. In September 1978, chemical analyses conducted by the Texas Department of Water Resources of water in the fly-ash ponds showed selenium levels of 2.2 to 2.7 mg/liter.

Shoreline counts of dead fishes were unreliable due to the slow nature of the die-off and delay or failure in reporting fish kills to the Texas Parks and Wildlife Department. Autopsies conducted during the die-off did not reveal the presence of parasites or bacteria in epidemic proportions. However, internal examination revealed enlarged kidneys and hemorrhaging in some specimens.

Analyses of fish muscle tissue from the reservoir by the Texas Department of Health revealed selenium concentrations ranging from 2.0 to 9.1 mg/kg (Table 2). This is considerably greater than 0.2 mg/kg recorded in February 1979 for largemouth bass, *Micropterus salmoides,* in uncontaminated Bellwood Reservoir in adjacent Smith County. Concentrations of mercury, copper,

Table 1. Trophic level groupings of fishes from Martin Creek Reservoir, Texas, 1977–1981.

Top carnivores	Omnivores
spotted gar (*Lepisosteus oculatus*)	common carp (*Cyprinus carpio*)
bowfin (*Amia calva*)	spotted sucker (*Minytrema melanops*)
blue catfish (*Ictalurus furcatus*)[a]	lake chubsucker (*Erimyzon sucetta*)
channel catfish (*I. punctatus*)[a]	black bullhead (*Ictaluras melas*)
flathead catfish (*Pylodictis olivaris*)[a]	yellow bullhead (*I. natalis*)
green sunfish (*Lepomis cyanellus*)[b]	tadpole madtom (*Notorus gyrinus*)
warmouth (*L. gulosus*)[b]	blue catfish (*Ictalurus furcatus*)[c]
largemouth bass (*Micropterus salmoides*)[b]	channel catfish (*I. punctatus*)[c]
white crappie (*Pomoxis annularis*)[b]	flathead catfish (*Pylodictis olivaris*)[c]
black crappie (*P. nigromaculatus*)[b]	green sunfish (*Lepomis cyanellus*)[d]
Planktivores	warmouth (*L. gulosus*)[d]
gizzard shad (*Dorosoma cepedianum*)	bluegill (*L. macrochirus*)
threadfin shad (*D. petenense*)	longear sunfish (*L. megalotis*)
golden shiner (*Notemigonus crysoleucas*)	redear sunfish (*L. microlophus*)
red shiner (*Notropis lutrensis*)	spotted sunfish (*L. punctatus*)
blacktail shiner (*N. venustus*)	bantam sunfish (*L. symmetricus*)
inland silversides (*Menidia beryllina*)	largemouth bass (*Micropterus salmoides*)[d]
	white crappie (*Pomoxis annularis*)[d]
	black crappie (*P. nigromaculatus*)[d]

[a] TL $\geqq$ 368 mm.
[b] TL $\geqq$ 114 mm.
[c] TL $\leqq$ 367 mm.
[d] TL $\leqq$ 113 mm.

zinc, manganese, and chromium were found to be similar in the 2 reservoirs. Selenium in muscle tissue of largemouth bass from 3 other coal-fueled power plant reservoirs in Texas averaged only 0.8 mg/kg.

In an unpublished report, Lind stated that the high concentration of selenium in surficial sediments (up to 14 mg/kg in 1982) was indicative of a recent addition and that this pollutant should continue to impact the Martin Creek Reservoir ecosystem for years to come. The latter assessment was based upon the low flushing rate for the reservoir and the presence of the Asian clam, *Corbicula* sp., whose deep-burrowing actions could delay removal by sedimentary processes.

Three years after the die-off, Sorensen et al. (1982*a*) found selenium concentrations as high as 6 mg/kg in skeletal muscle of redear sunfish, *Lepomis microlophus,* at Martin Creek Reservoir. This is well above the 2-mg/kg level recommended by the National Health and Medical Research Council of Australia as a maximum in seafoods consumed by humans (Bebbington et al. 1977). Sorensen has published extensively on physiological maladies of redear and green sunfish, *L. cyanellus,* exposed to selenium in Martin Creek Reservoir. These include reduced hematocrits, lower hemoglobin concentrations, changes in leukocyte distribution, small, irregularly shaped erythrocytes, reduced mean corpuscular volume, reduced mean corpuscular hemoglobin concentration

Table 2. Selenium concentration (mg/kg) in fish muscle tissues, Martin Creek Reservoir, Texas, from analyses conducted by Texas Department of Health. Sample sizes >1 are given in parentheses.

Species	2/79	4/79	7/79	3/80	4/81	2/82
Spotted gar		2.0			3.0	
Gizzard shad	7.0	5.6	7.3	5.3 (2)	5.1 (4)	2.9 (9)
Common carp		9.1 (2)	4.6	4.6	5.6 (2)	3.6 (4)
Channel catfish	3.2	2.7 (7)	4.6 (3)	2.8 (8)	3.3	2.7
Largemouth bass	7.1		8.3 (3)	6.2 (8)		3.8 (14)
Redear sunfish				5.6 (8)		4.4 (4)
Bluegill		6.8 (5)		5.8 (8)		3.4 (5)
Longear sunfish				5.1 (6)		
Black crappie				6.8 (2)	5.4	

(Sorensen and Bauer 1983), kidneys with proliferative glomerulonephritis, hematuria and necrosis of convoluted tubule cells (Sorensen et al. 1982a, 1982*b*, 1983), central necrosis and increased numbers of phagocytotic reticuloendothelial cells in hepatic tissue (Sorensen et al. 1982, 1983), reduced hepatopancreas-weight-to-body-weight ratio (Sorensen and Bauer 1984), hypertrophy of exocrine pancreas tissue (Sorensen et al. 1983), vacuolated and thickened gill lamellae and ovaries with an increased number of atretic follicles (Sorensen et al. 1982*a*).

Following the die-off in 1978, fish community structure was altered considerably. Total fish biomass was reduced by 11% in 1979; however, this percentage is understated since 154 common carp accounted for 70% of the total weight recovered. Common carp have been shown to be relatively resistant to selenium poisoning (Huckabee and Griffith 1974). Without common carp in either the 1977 or 1979 samples, the standing crop was reduced 72%. The greatest declines in biomass were sustained by planktivorous and carnivorous fishes while omnivores increased (Fig. 1). Planktivores changed from the largest to the smallest group, carnivores were reduced by nearly half, and omnivores became the largest group at 4 times their original size. By 1981, planktivore biomass remained the lowest, carnivores had recovered to approximately 90% of their original biomass, and omnivores continued to dominate the community at 3 times their original abundance.

Two of the more prominent planktivores in Martin Creek Reservoir were gizzard shad, *Dorosoma cepedianum,* and threadfin shad, *D. petenense.* Gizzard shad density was reduced from 889.7/ha in 1977 to 181.6/ha in 1979 and had recovered to only 263.8/ha by 1981. Threadfin shad numbers were also reduced (130/ha to 6.4/ha), but greatly recovered in 1980 (271.5/ha).

The deleterious effects of selenium may have also influenced interspecific competition in the above instance. It is conceivable that a species could actually realize a net benefit from selenium contamination if selenium affected a competitor to an equal or greater degree and the effects of competition were more detrimental to this species than the effects of selenium. Both

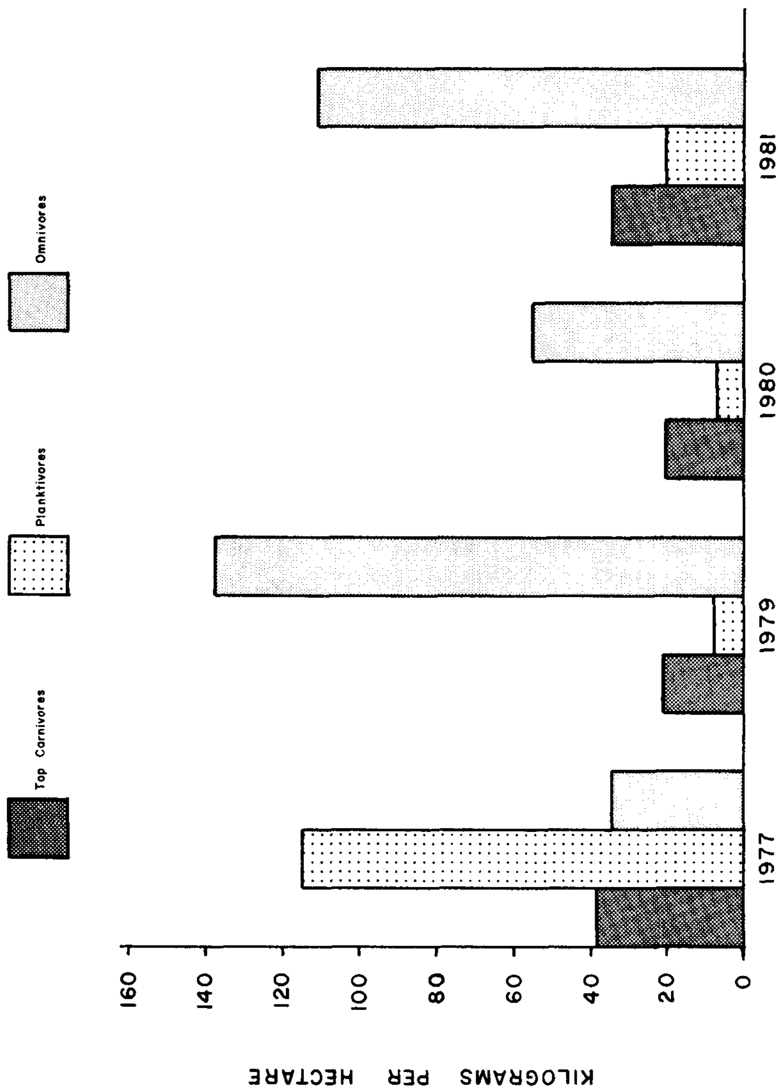

Figure 1. Fish biomass by trophic groups from cove rotenone sampling, Martin Creek Reservoir, Texas, July, 1977, 1979, 1980, and 1981.

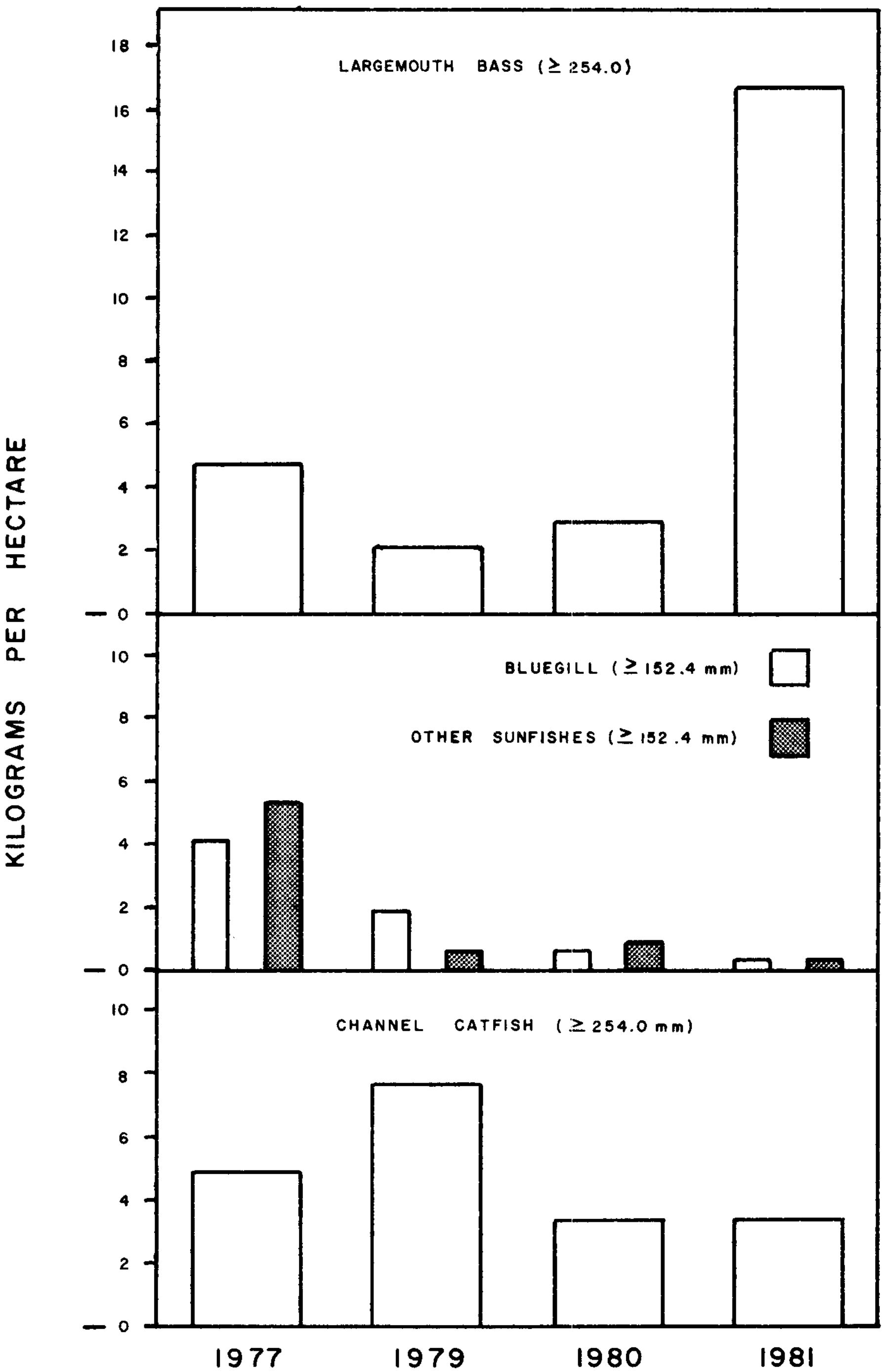

Figure 2. Biomass of harvestable-size sport fishes from cove rotenone sampling, Martin Creek Reservoir, Texas, July, 1977, 1979, 1980, and 1981.

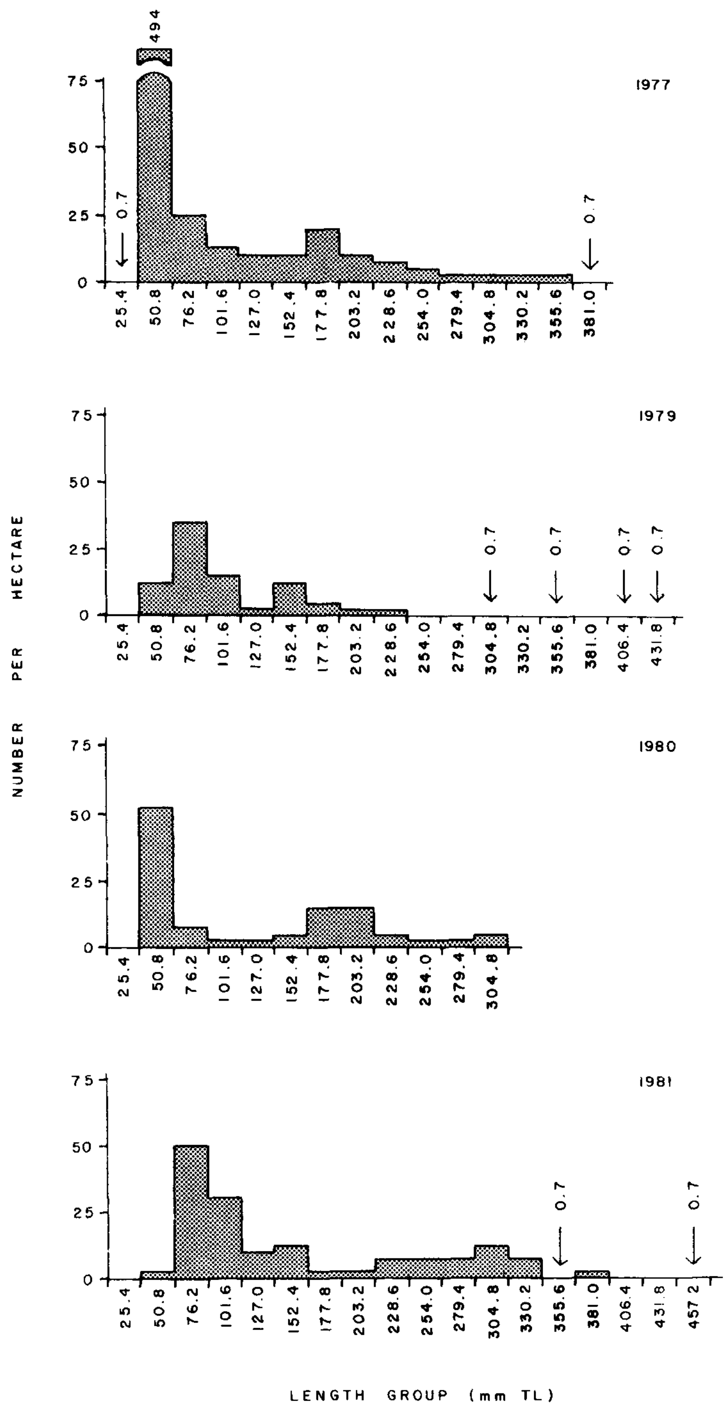

Figure 3. Length-frequency distribution of largemouth bass from cove rotenone sampling, Martin Creek Reservoir, Texas, July, 1977, 1979, 1980, and 1981.

threadfin and gizzard shad suffered a numerical decrease after the selenium release; however, in 1980 threadfin shad were actually in greater abundance than before the discharge. Gizzard shad did not show signs of recovery until 1981, at which time the threadfin shad began to decline again (to 88.4/ha). Total shad density in 1981, however, remained below the 1977 pre-selenium level (1,019.7/ha in 1977 and 352.2/ha in 1981).

One of the more important carnivores in Martin Creek Reservoir is the channel catfish, *Ictalurus punctatus*. Biomass of adult channel catfish, after increasing in 1979, fell below the 1977 level in 1980 and 1981 (Fig. 2). The 1-year delay in biomass reduction suggests that adults may have had a higher tolerance to selenium than some of the other species in this study. Cumbie and Van Horn (1978) reported that adult channel catfish appeared to be less sensitive to selenium than are centrarchids.

Adult largemouth bass biomass was reduced in 1979, began increasing by 1980, and by 1981, biomass of harvestable-size largemouth bass had far surpassed the 1977 pre-selenium level (Fig. 2). Length-frequency distribution indicated these fish were probably spawned in 1979 (Fig. 3) accounting for the majority of the yearlings (178–229 mm TL) in 1980 and adults in 1981. Several factors may have contributed to enhanced survival of this year class. The die-off in 1978 probably reduced inter- and intraspecific competition as well as predation at a critical time in their life. Additionally, human predation (angler harvest) was certainly reduced due to publicity concerning selenium contamination in the reservoir.

While conditions for harvestable largemouth bass may have improved by 1981, reproductive success remained detrimentally affected as indicated by the low numbers of young-of-the-year in 1979 and 1980 (Fig. 3). This is not surprising in light of evidence that selenium accumulates in organisms over time (Kaiser et al. 1979) and has a detrimental effect on fish reproduction (Cumbie 1978, Cumbie and Van Horn 1978).

Biomass of sunfishes, *Lepomis* spp., was reduced following the selenium discharge with fewer quality (≥152 mm TL) sunfishes in the 1979, 1980, and 1981 collections (Fig. 2). Population density, however, increased during the 1979 spawning season and continued the following year with a 62% increase in number over the 1977 level (4,038/ha in 1977 and 6,511/ha in 1980). Reduced predation, due to a lower number of carnivores, probably permitted substantial survival of young sunfishes resulting in an increase in population density and an undesirable population balance.

If no additional selenium were added to Martin Creek Reservoir, many years might still be required before the existing contamination of this ecosystem is reduced to natural levels. So far, the contamination seems to have drastically altered the fish community structure. The relative abundance of planktivores versus omnivores remains reversed from the pre-contamination relationship. The increase in available forage (e.g., small sunfishes) is certainly beneficial to piscivores, but since this increase was probably due to reduced predation and competition, it may be short-lived. Numbers of quality-size channel catfish and sunfishes were greatly reduced and have remained low. While there are now more adult largemouth bass present, reproduction remains detrimentally affected. Even if selenium concentrations eventually return to an acceptable level, fish community structure in this reservoir may not necessarily return to pre-contamination proportions.

Cooperation between state agencies and private consultants enabled the Texas Parks and Wildlife Department to observe selenium levels in the reservoir and effect a management program to reduce selenium releases and improve conditions in the lake. The department is now involved in a long-term program of monitoring selenium in sediments and fish tissue, monitoring the fish community, and restocking certain fish species in an attempt to restore this system.

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