SELENIUM ACCUMULATION ASSOCIATED WITH FISH MORTALITY AND REPRODUCTIVE FAILURE

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Abstract: Fish populations of Belews Lake, North Carolina, declined during the period of operation of the Belews Creek Steam Station from 1974 through 1977. Reproduction of fish in the main lake was almost completely absent in 1976 and 1977. A survey of trace elements in water and fish from Belews Lake indicated that selenium concentrations were elevated in Belews Lake water, and that fish in the lake had accumulated unusual amounts of selenium. Fish from a remote area of Belews Lake where normal reproduction took place in 1976 and 1977 had much lower selenium concentrations in their tissues than fish from the main basin. Only trace elements of selenium occur naturally in water, soil, or mineral deposits in the Belews Lake drainage. Selenium entered Belews Lake in soluble form by way of the power plant fly ash sluice water return. Selenium concentrations in Belews Lake water were not high enough to be directly toxic to fish. Uptake by plankton introduced selenium to the food chain where it ultimately reached elevated levels in fish due to bioaccumulation. Selenium is known to interfere with reproduction in animals, and is considered to be the most probable cause of reduced fish reproduction in Belews Lake. The North Carolna Department of Natural Resources and Community Development and Duke Power Company have taken action to reduce inputs of selenium to Belews Lake.

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The fish populations of Belews Lake were studied by the North Carolina Wildlife Resources Commission Division of Inland Fisheries from 1971 through 1976. As a continuation of that fisheries program, Duke Power Company initiated a study of the fish populations of Belews Lake and their responses to its thermal regime in July 1976 (Harrell et al. 1978). The results of these studies indicated that fish standing crops in Belews Lake were extremely low by the fall of 1976, on the order of 25 kg/ha or less, and had declined during the period from 1973 through 1976. Reproduction of all species was normal prior to 1975, but reproduction declined and all but disappeared in 1976. Rotenone sampling conducted in September 1976 yielded almost no young-of-the-year fishes from Belews Lake.

Intensive sampling for larval fish in the spring and summer of 1977 detected only carp (*Cyprinus carpio*) larvae in the main lake (Harrell et al. 1978). Concurrent investigation of an area separated from the main lake by 2 highway causeways which largely restrict exchange of water with the main lake to downstream flow (Station 158, Fig. 1) revealed that apparently normal fish populations persisted in those waters, dominated by sunfishes (*Lepomis* spp.) and catfishes (*Ictalurus* spp.). Larvae and young-of-the-year fishes were collected from Station 158 in the spring of 1977, indicating that reproduction was occurring in that area.

These observations suggested that fish reproduction and possibly adult fish survival had been adversely affected by factors associated with the main basin of Belews Lake which were absent at Station 158. A number of possible causes for this situation were considered, including (1) unusually poor year class strength associated with unfavorable environmental factors such as water level, temperature, etc.; (2) unbalanced population structure resulting in poor reproductive success; (3) mortality due to thermal effects in certain areas; (4) losses due to impingement and entrainment; (5) adverse effects of diseases or parasites; and (6) mortality and reproductive failure due to effects of

chemicals. Examination of the available data resulted in elimination of factors (1) through (5) as probable causes. Investigation of the influence of chemical factors is described in this report.

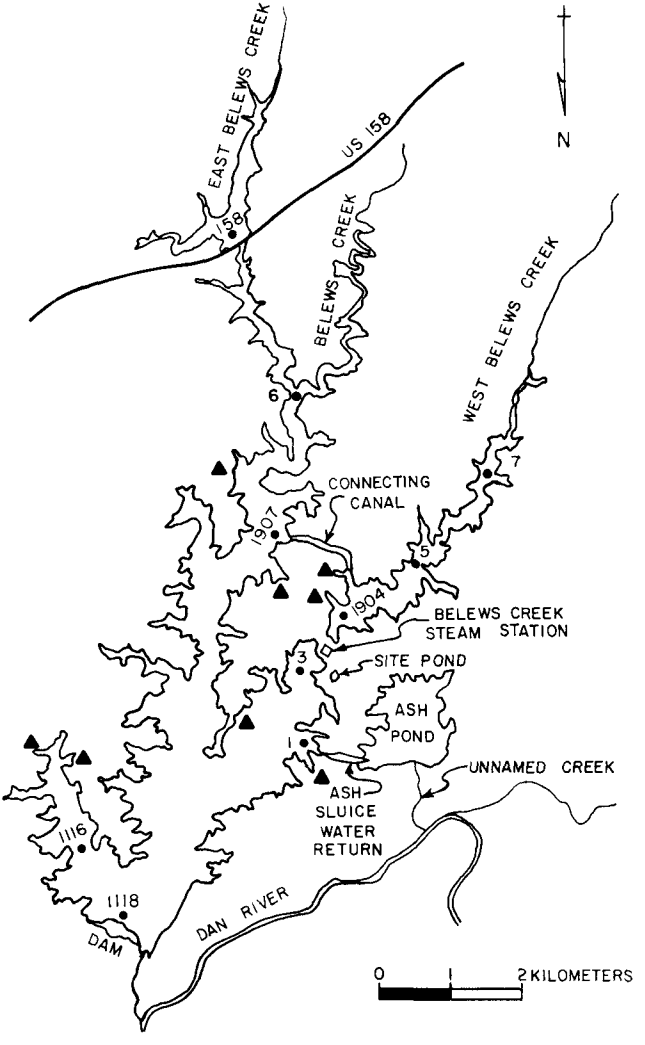

Fig. 1. Belews Lake, North Carolina. Solid circles represent fish, water quality, and/or plankton sampling stations. Solid triangles represent locations of rotenone sampling coves.

J. N. Weaver, North Carolina State University, Raleigh; G. N. Schrauzer, University of California at San Diego; L. L. Ball, Carolina Power and Light Company; and Stewart Laboratories, Knoxville, TN, performed analyses of fish tissues and other materials. The Duke Power Company Environmental and Power Chemistry Analytical Laboratories collected samples and performed chemical analyses of water. The cooperation of J. C. Leathers and R. E. Green of the Belews Creek Steam Station is greatly appreciated. The North Carolina Wildlife Resources Commission studies were partially supported by D-J Project F-23-1, North Carolina.

MATERIALS AND METHODS

Fish Population Study

Eight coves in Belews Lake averaging 0.4 ha each were selected in 1973 for rotenone study of fish populations (Fig. 1). A 90 m block net with a 1.3 cm bar mesh was used to isolate each cove. A gasoline-powered pump and perforated, weighted hose were used to deliver 5% emulsifiable rotenone to a final estimated concentration of 0.5 mg/l in the water column. Fish were collected on the day of rotenone application and the following day. The fish were sorted by species into 2.5 cm size classes, counted, and weighed. The coves were rotenoned each September from 1973 through 1976.

Elemental Analysis

Fish specimens for elemental analysis were collected during 1976 and 1977 by electrofishing, gill-netting, rotenone, or hook-and-line. Tissues were stored frozen in polyethylene containers for elemental analysis, and were handled with carbon steel or teflon-coated instruments.

Special water samples were collected using Kemmerer or Van Dorn sampling bottles, filtered through 0.45 μm membrane filters, and acidified with nitric acid. Certain water chemistry data for the Belews Creek Steam Station were supplied by the Duke Power Company Steam Production Department.

Plankton were collected using a No. 18, 80 μm mesh net hauled vertically from a depth of 10 m to the surface. A sufficient number of separate hauls (5 to 10) were taken at each location to insure that a representative plankton sample large enough for analysis was obtained. No attempt was made to separate zooplankton from phytoplankton. The concentrated plankton suspensions were stored frozen in polyethylene containers. For analysis, plankton were collected by filteration, dried at 60 C, and weighed on an analytical balance. Plankton analyses are reported as μg of element per gram (ppm), dry weight basis.

Elemental analysis was performed by neutron activation or by atomic absorption spectrophotometry techniques. Neutron activation analysis of fish tissue and plankton was performed at the Nuclear Services Laboratory, North Carolina State University, Raleigh, by a non-destructive technique using appropriate internal standards and NBS reference materials for calibration. Certain specimens were analyzed at the University of California at San Diego by the fluorometric technique (Olson 1969) or at the Carolina Power and Light Company Chemistry Laboratory, New Hill, North Carolina, by the selenium hydride atomic absorption technique as checks on the neutron activation method. Results of fish analyses are reported as μg of element per gram (ppm), wet weight basis.

Water samples were generally analyzed for elemental content by graphite furnace atomic absorption techniques in the Duke Power Company Steam Production Department laboratories, using a Perkin-Elmer Model 306 spectrophotometer with the HGA 2100 graphite furnace atomizer. Chemicals used in the analyses were analytical reagent grade. Certain water analyses were also performed by neutron activation analysis at North Carolina State University, or by the selenium hydride generation technique at Stewart Laboratories. Water analyses were reported as μg element per liter (ppb).

Study Area

Belews Lake is a Duke Power Company impoundment located in Forsyth, Guilford, Rockingham, and Stokes Counties, North Carolina. The primary purpose for the construction of Belews Lake was to provide a source of cooling water for Belews Creek Steam Station. The Belews Creek Steam Station is a coal-fired electrical generating station which consists of 2 units, each rated at 1140 megawatts. The first unit was placed in service in August 1974, the second in December 1975.

Belews Lake reached a full pond elevation of 221 m msl in 1973. It has a surface area of 1563 ha, a volume of 2.3×10^8 m^3, a maximum depth of approximately 44 m, and a mean depth of 15 m. The average retention time of the lake is approximately 1500 days.

Condenser cooling water is withdrawn from the main body of Belews Lake through a surface intake and is discharged to the West Belews Creek arm (Fig. 1). The West Belews Creek arm is connected to the main lake below the confluence of Belews Creek and East Belews Creek by a canal. Intake water is also used to transport fly ash and bottom ash from the station to an ash basin, where the ash is collected by settling. Overflow from the ash basin enters the west side of Belews Lake through the ash sluice water return (Fig. 1). Water quality data for Belews Lake have been collected regularly since impoundment (Weiss et al. 1974).

RESULTS AND DISCUSSION

Fish Population Study

A total of 29 species of fish was collected in Belews Lake rotenone samples from 1973 through 1976. A summary of the standing crop data for all species combined and for bluegill (*Lepomis macrochirus*), green sunfish (*L. cyanellus*), largemouth bass (*Micropterus salmoides*), flat bullhead (*Ictalurus platycephalus*) and threadfin shad (*Dorosoma petenense*) is presented in Table 1. The more noticeable features of the data are the large increase in numbers of fish per ha in 1975 followed by a sharp decline in both average numbers and weight per ha in the 1976 rotenone sample. The 1975 increase in numbers was caused by an introduction of threadfin shad and the presence of large numbers of young-of-the-year for many of the non-shad species. In 1976 few shad were collected, the numbers and weights of many non-shad populations had declined, and the 1976 year-class for most species was nearly absent. An increase in weight was measured for only 5 species of fish in the 1976 sample: green sunfish, redear sunfish (*L. microlophus*), flat bullhead, black bullhead (*I. melas*), and black crappie (*Pomoxis nigromaculatus*). Redear sunfish accounted for less than 3% of the total sample by weight and black crappie less than 1%.

To illustrate the near absence of a 1976 year-class for fishes in the main body of Belews Lake, Table 2 presents young-of-the-year composition for bluegill, green sunfish, largemouth bass, and flat bullhead populations recovered in rotenone samples from 1973 through 1976. Young-of-the-year fish were defined to be those individuals whose total lengths were included in the following size ranges: bluegill, 0-64 mm; green sunfish 0-64 mm; largemouth bass, 0-114 mm; and flat bullhead, 0-89 mm. These values were determined from length-frequency distributions constructed for each species using the fish collected in the 1973 through 1975 rotenone samples. Age-growth information obtained by scale analysis was used to verify the young-of-the-year size ranges for bluegill and largemouth bass. No fish in the 0-64 mm size range were recovered in the 1976 rotenone sample for any of 9 centrarchid species collected. Only 8 black and flat bullheads were recovered which were within the projected young-of-the-year size range. The number of threadfin shad taken in the rotenone samples dropped from 20,295 individuals in September 1975 to 24 individuals in September 1976, indicating failure of the 1976 threadfin shad year-class. Subsequent investigations by Duke Power Company in 1977 and 1978 (Harrell et al. 1978) have indicated that diverse fish populations persist at

Table 1. Standing crop information from 8 rotenone coves on Belews Lake, 1973-1976. Total area sampled was 3.2 ha. Data are mean standing crop (g/ha) followed by mean population density (number of individuals/ha) for the indicated species and for all species combined.

Year	*Total (29 species)*	*Lepomis macrochirus*	*Lepomis cyanellus*	*Micropterus salmoides*	*Ictalurus platycephalus*	*Dorosoma petenense*
1973	113608	34854	2857	11069	3447	0
	(7198)	(3502)	(410)	(277)	(69)	(0)
1974	76948	28964	1920	6682	1276	<1
	(5297)	(2941)	(244)	(111)	63)	(1)
1975	86680	26178	1102	4958	3896	17180
	(13630)	(4117)	(253)	(237)	(344)	(6264)
1976	27099	7330	3056	6	7683	46
	(840)	(301)	(103)	(<1)	(173)	(7)

Table 2. Young-of-the-year composition for 4 Belews Lake fish species collected in cove rotenone samples. Data are percentage of population represented by young-of-the-year followed by number of young-of-the-year collected in the 3.2 ha sampling.

Year	*Lepomis macrochirus*	*Lepomis cyanellus*	*Micropterus salmoides*	*Ictalurus platycephalus*
1973	52.0	52.2	70.7	45.1
	(5900)	(695)	(634)	(101)
1974	70.3	63.8	60.4	76.3
	(6704)	(504)	(218)	(155)
1975	69.9	85.0	92.3	79.5
	(9322)	(696)	(710)	(886)
1976	0	0	0	1.1
	(0)	(0)	(0)	(6)

Station 158. Fish at Station 158 exhibited apparently normal reproductive sucess during 1977 and 1978, in marked contrast to the continued lack of reproduction in the main body of Belews Lake.

Numerous environmental factors affect reproduction and strength of year-class in fish populations. Year-class strength is highly variable and may show extreme year-to-year fluctuations (Heidinger 1975, Summerfelt 1975). However, complete absence of a year-class is highly unusual. A poor year-class may often be related to recognizable chemical or physical factors which (a) interfered with successful spawning of adult fish, (b) prevented successful hatching of eggs, or (c) caused excessive mortality of fish larvae after hatching.

Environmental and operational data for Belews Lake and the Belews Creek Steam Station were examined to identify any such factors. Although Belews Lake water levels were low during 1976, extreme fluctuations which would interfere with nesting activities did not occur. Nesting and spawning activities were observed in the lake during the spring of 1976 (Harrell et al. 1978). Entrainment of larvae or young fish could contribute to losses, but would not be expected to cause 100% mortality in a year-class. Meteorological

data do not indicate that extreme adverse weather conditions occurred during the 1976 spawning season. Elevated water temperatures occurred in only a limited portion of the lake, and would not have influenced spawning or adult survival outside the discharge areas. Abnormal rates of parasitic infestation or disease have not been detected in fish from Belews Lake, nor were accumulations of pesticides detected (Duke Power Company unpublished data). The patterns of fish mortality and absence of young fish could not be related to the distribution of heated water during power plant operation (Harrell et al. 1978).

Water Chemistry

The chemical environment in Belews Lake is described in Table 3. Belews Lake water is relatively low in alkalinity and nutrients and most chemical characteristics were comparable among stations. However, selenium and arsenic concentrations were higher at main lake stations than at Station 158. Concentrations of selenium in surface water displayed a seasonal variation with highest values recorded during the summer and fall stratified period. Dissolved selenium and arsenic entered Belews Lake in ash basin effluent from the Belews Creek Steam Station. Selenium tended to remain in solution, probably as a mixture of SeO_3^{-2} and SeO_4^{-2}, in the epilimnetic waters of the lake during the spawning season. The limnological and chemical properties of selenium and arsenic have been more completely described elsewhere (Ferguson and Gavis 1972, Lakin 1973, Cumbie 1978).

Fish Elemental Analyses

Fish collected from Belews Lake in October and November 1976 were analyzed for trace elements and heavy metals by neutron activation analysis. Sixteen elements were detected in composited fish skeletal muscle tissues. Concentrations of 15 of these elements (Sb, Br, Sc, Fe, Co, Cr, Mn, Cl, Na, K, V, Ti, As, Zn, and Hg) could not be associated with the observed condition of fish populations in Belews Lake. The data of Table 4 for As, Fe, and Cr are typical of the results obtained for these elements. In contrast, selenium concentrations in these fish were elevated in main basin specimens compared to those from Station 158 (Table 4).

Table 3. Water quality data for Belews Lake, 1976-1977. Values are annual means of filtered surface water samples, except as indicated (Cumbie 1978, Weiss et al. unpublished). Conductivity is in μmhos/cm; hardness in mg/l $CaCO_3$. All ionic values are in mg/l except As and Se which are in μg/l.

Location	*pH*	*Cond*	*Hardness*	*SO_4*	*Cl*	*Ca*	*Mg*	*K*	*Na*	*As*[a]	*Se*[a]
Main Lake	7.5	113	38.2	16.7	3.2	11.4	2.4	3.9	4.4	7	10
158	7.1	74	23.8	7.1	3.1	6.0	2.2	2.3	4.0	<2	<5

[a]Se and As data are for unfiltered samples. Filtration of selected samples indicated no difference in Se or As concentration for filtered and unfiltered lake water. Detection limits for Se and As were 5 and 2 μg/l, respectively.

Additional fish specimens were collected between March and September 1977 and analyzed individually for selenium content. Selenium concentrations (Tables 5 and 6) were much higher in all species collected from the main lake (Stations 3, 6, 1116, 1904, and 1907) than in those collected from Station 158. Selenium concentrations in Station 158 fish could not be correlated with length or weight of individuals within species. Due to the small numbers of fish which were collected from the main portion of Belews Lake in 1976 and 1977, no relationships between length or weight and selenium concentration could be established. Other investigators have also reported a lack of consistent relationships between tissue selenium concentration and size, sex, or species of fish (Adams 1976, Pillay et al. 1974, Pakkala et al. 1972). However, consistently large differences existed between selenium concentrations of Station 158 fish and those from the main lake for all species and/or similar size classes. Mean selenium concentrations in skeletal muscle of fish from Station 158 fell in the range of 0.5 to 7 ppm (wet weight), while mean concentrations in fish from the main lake stations ranged from approximately 10 to 50 ppm. This pattern of selenium accumulation was closely associated with the observed patterns of population decline and reproductive failure of fish in Belews Lake.

Table 4. Selected elemental concentrations in composited fish skeletal muscle specimens from Belews Lake, North Carolina, and from the Belews Creek Steam Station site pond. Analyses were performed by instrumental neutron activation analysis, Nuclear Services Laboratory, N.C. State University, Raleigh. All concentrations are ppm, wet weight.

Species	*No. in Composite*	*Station*	*Se*	*As*	*Fe*	*Cr*
Lepomis auritus	2	158	1.55	<0.1	24.8	0.19
L. macrochirus	5	158	4.12	2.65	<10	0.09
L. microlophus	4	158	1.10	0.32	<10	0.14
Ictalurus spp.	4	1904	11.3	0.34	25.9	0.27
Lepomis spp.	4	1904	22.3	<0.1	22.6	1.69
Ictalurus spp.	2	1116	7.96	<0.1	26.7	0.21
L. macrochirus	3	1116	10.6	<0.1	27.3	0.05
L. gulosus	2	1116	19.2	<0.1	15.5	0.28
L. cyanellus	4	Pond	1.53	0.1	a	a

[a]not determined

As a check of the analytical results obtained by the neutron activation technique, replicate specimens of fish skeletal muscle were analyzed by the fluorometric method (Olson 1969) and by the selenium hydride AA technique. The results indicated that neutron activation may give somewhat higher selenium values than the fluorometric method (Table 7). However, the 2 methods gave results which were consistent when the high and low selenium concentrations were compared. Results of the AA technique were in close agreement with those obtained by neutron activation. Analysis of NBS Standard Reference Material No. 1632 (coal) and NBS Research Material No. 50 (fish tissue) also indicated agreement of the neutron activation results with the reference values for selenium.

Table 5. Selenium concentrations detected in Belews Lake fish, Stations 1907, 1904, 1116, 6 and 3, March-September, 1977. Analysis as in Table 4, all concentrations ppm wet weight.

Species	*Station*	*Sample Size*	*Date*	*Mean [Se]*	*S.D.*	*Range*
Lepomis cyanellus	1904	3	March 1977	9.62	5.87	3.40-15.1
Ictalurus spp.	1904	10	"	6.58	3.34	1.76-12.6
C. carpio	1904	5	"	12.0	3.01	6.77-14.2
Ictalurus spp.	1904	6	May 1977	7.77	2.29	5.10-10.4
Ictalurus spp.	1116	5	"	6.32	5.79	0.31-15.5
L. gulosus	1904	3	June 1977	9.64	4.65	4.28-12.6
L. macrochirus	1904	2	"	9.89	11.3	1.93-17.9
L. macrochirus	1907	1	"	6.55	---	---
L. microlophus	1116,3	2	"	31.5	7.1	26.5-36.5
I. punctatus	1904	3	"	26.1	4.17	22.3-30.6
Ictalurus spp.	1904,1116	7	"	11.25	4.52	3.46-15.3
Lepomis spp.	3,1116	3	September 1977	54.6	19.6	41.0-77.1
Ictalurus spp.	3,1116	6	September 1977	23.6	8.74	10.1-36.2
C. carpio	3,1116	4	"	29.33	10.49	14.1-36.7
L. macrochirus	6	4	"	17.2	7.12	8.89-25.9
L. microlophus	6	1	"	21.1	---	---
L. gulosus	6	4	"	19.6	5.01	13.9-25.5

Table 6. Selenium concentrations detected in Belews Lake Station 158 fish, March-September, 1977. Analysis as in Table 4, all concentrations ppm wet weight.

Species	*Sample Size*	*Date*	*Mean [Se]*	*S.D.*	*Range*
Lepomis auritus	2	March 1977	4.31	2.38	2.63-5.99
L. macrochirus	2	"	3.40	1.50	2.34-4.46
L. gulosus	8	"	3.90	0.64	3.06-5.03
L. cyanellus	6	"	2.11	0.43	1.42-2.69
Ictalurus spp.	10	"	0.57	0.36	<0.10-1.16
Cyprinus carpio	4	"	2.95	1.76	1.46-5.49
L. macrochirus	12	Sept. 1977	6.98	3.78	2.90-13.4
L. gulosus	12	"	6.71	1.96	3.56-10.2
L. cyanellus	8	"	2.94	0.51	2.14-3.63
L. microlophus	5	"	2.21	0.55	1.30-2.73

Control specimens of green sunfish and bluegill were obtained from a pond on the Belews Creek Steam Station site and from Lake Norman, North Carolina. The power plant site pond is located behind an access roadbed leading to the Belews Creek Steam Station (Fig. 1). It drains through a culvert from which the overflow falls approximately 2.5 m through rip-rap to the lake. This pond supported a population of small sunfishes which was physically isolated from Belews Lake. Skeletal muscle from these fish contained between 1 and 4 ppm selenium, a range of concentrations similar to that seen in

Table 7. Comparison of replicate Se analyses by neutron activation analysis (NAA), fluorometric analysis (FA), and atomic absorption spectrophotometry (AA). Fish tissue ppm, wet weight; SRM and RM materials ppm, dry weight.

Sample No.	*Se*, $\mu g/g \pm$ *S.D.*: *NAA*	*FA*	*NBS*	*AA*
Fish 977-19	23.9 ± 3.4	14.2 ± 0.5	---	---
Fish 977-59	3.70 ± 0.56	2.58 ± 0.03	---	---
SRM 1632	2.96 ± 0.33	---	2.9 ± 0.3	
RM 50	3.01 ± 0.13	---	3.6 ± 0.4	---
Fish 677-53	12.3 ± 1.2	---	---	11.9[a]
Fish 1078-21	2.20 ± 0.17	---	---	2.3[a]

[a]Single analysis.

fish from Belews Lake Station 158. Lake Norman is a major impoundment on the Catawba River, located approximately 120 km southwest of Belews Lake, and contains healthy and diverse fish populations (Duke Power Company 1975). The Lake Norman specimens contained an average of 0.7 ppm selenium. These data indicated that selenium had been concentrated in Belews Lake fish to levels much higher than those found in fish from other nearby waters.

A limited number of fish in spawning condition were obtained from Belews Lake and from the power plant site pond during May and June 1977. Tissues from these fishes were analyzed for total selenium content to compare selenium accumulation in skeletal muscle to accumulation in reproductive organs. Female *Lepomis* spp. and *Ictalurus* sp. from both Belews Lake and the site pond exhibited 1.5- to 3-fold higher selenium concentrations in ovaries than in skeletal muscle of the same individuals (Table 8). This tendency appeared to be more pronounced in the sunfishes than in the catfishes. Only 2 ripe male *Lepomis* were collected from Belews Lake; in both individuals the concentration of selenium in testis was slightly lower than that in skeletal muscle. This was in contrast to the consistent tendency for ovarian selenium concentrations to be higher than those in skeletal muscle.

Although these data are limited, they indicate that selenium accumulates in gonadal tissue to an extent approximately equal to (males) or exceeding (females) that in skeletal muscle. This suggests that adverse effects on egg fertilization, embryonic development, or survival of newly hatched larvae might result where fish accumulate unusually high concentrations of selenium in their tissues. Selenium is known to interfere with reproduction in mammals and has been associated with adverse effects on the female reproductive system (EPA 1966b). Although the ovary does not contain significant amounts of selenium under normal conditions, it will accumulate high concentrations when unusual exposure occurs. This accumulation of selenium can prevent production of viable offspring.

Selenium and arsenic concentrations in Belews Lake water are low compared to concentrations which are acutely toxic to fish (Cardwell et al. 1976, EPA 1976a, Niimi and LaHam 1975). Therefore, it was hypothesized that deleterious effects of selenium on Belews Lake fish resulted from bioaccumulation through the food chain. As a measure of the possible movement of selenium into food chains in Belews Lake, plankton were analyzed for selenium and arsenic content.

Selenium concentrations in plankton from the mainbasin of Belews Lake were much higher than those in plankton collected at Station 158 (Table 9). Station 158 plankton

Table 8. Selenium concentrations in gonads and skeletal muscle of fish from Belews Lake and Belews Creek site pond, June 1977. Analysis as in Table 4, all concentrations ppm wet weight.

Species	Specimen No.	Station	Se Concentration			Ratio
			Skeletal Muscle	Ovary	Testis	Gonad/Skeletal Muscle
Lepomis gulosus	1	1904	12.6	34.6	---	2.74
	2	"	12.0	31.0	--	2.58
	3	"	4.28	13.7	---	3.20
L. macrochirus	1	1907	17.8	--	15.2	0.85
	2	1904	1.93	5.29	--	2.74
L. cyanellus	1	B. C. Pond	1.94	3.18	--	1.64
	2	"	4.36	18.7	--	4.28
	3	"	1.84	3.00	--	1.63
	4	"	1.05	1.57	--	1.49
	5	"	1.43	4.73	--	3.31
L. microlophus	1	1116	26.5	28.2	--	1.06
	2	3	36.5	--	22.8	0.62
Ictalurus melas	1	1116	13.8	20.7	--	1.50
	2	1904	14.4	20.9	--	1.45
	3	7	15.3	41.7	--	2.72

contained approximately 4 to 20 ppm selenium (dry weight), while plankton from Station 3 contained from 40 to 100 ppm selenium. On a wet weight basis (assuming that dry weight of zooplankton is 5% of wet weight) these figures would be approximately 0.8 and 3.0 ppm, respectively. In contrast, arsenic concentrations in plankton did not differ consistently between the 2 locations. The higher concentrations of selenium present in Station 158 plankton in November 1977 may have resulted from uplake movement of surface water caused by strong winds observed at the time of collection, which could transport plankton to Station 158 from areas immediately downlake. Although few data are available for comparison, other investigators have found plankton to be efficient accumulators of selenium (Sandholm et al. 1973). Copeland and Ayers (1972) reported a selenium concentration of 0.60 ppm (wet weight) for zooplankton from Lake Michigan.

Several reports have indicated that long-term ingestion of as much as 5 ppm selenium (dry weight) in the diet of domestic livestock or fish will result in selenium poisoning and associated disorders (Oldfield et al. 1974; J. P. Goettl, personal communication). Fish in Belews Lake which fed on zooplankton or small fish were apparently exposed to dietary selenium levels which equaled or exceeded this concentration.

Available data indicate that selenium concentrations in fish muscle tissues rarely exceed 1 ppm (wet weight) in the absence of exposure to selenium from geologic sources such as alkaline soils of the western United States or from industrial wastes. Investigations conducted in New York (Pakkala et al. 1972), central Canada (Beal 1974), Lake Erie (Adams 1976, Pillay et al. 1974), Michigan (Hesse and Evans 1972), the Great Lakes area (Copeland et al. 1973, Traversy et al. 1975, Uthe and Bligh 1971), Utah (Pratt et al. 1972), and South Carolina (J. P. Giesy, Jr., personal communication) have reported selenium concentrations in fish muscle ranging from 0.1 to 1.5 ppm (wet weight).

The exceptions to these observations are of interest. Cherry et al. (1976) reported that mosquitofish (*Gambusia affinis*) accumulated high concentrations of selenium in muscle tissue, averaging 9 ppm (wet weight), in a drainage system which received ash basin effluent containing 107 μg/l total selenium from a coal-fired power plant. There

Table 9. Selenium and arsenic concentrations (ppm dry weight) in plankton from Belews Lake, March - November, 1977. Data are mean selenium concentrations ± standard deviation for duplicate analyses.

Element	*Station*	*March*	*June*	*July*	*August*	*November*
Se	3	41.3 ± 6.6	53.7 ± 22.6	97.0 ± 2.3	70.4 ± 2.0	42.8 ± 9.5
	158	4.3 ± 0.9	16.5 ± 4.7	16.5 ± 1.8	21.1 ± 0.9	29.3 ± 1.7
As	3	---	3.1 ± 0.3	9.4 ± 1.7	7.7 ± 1.3	11.3 ± 4.0
	158	---	2.3 ± 1.5	4.0 ± 3.5	5.4 ± 4.7	2.0 ∓ 1.2

was no indication of an effect of this concentration of selenium or reproduction of the fish. However, no other species of fish were found in the drainage from which the mosquitofish were collected, and mosquitofish are known to be highly resistant to a variety of pollutants (Cherry et al. 1976). Mosquitofish were also present and reproducing in the main basin of Belews Lake in 1977 (Harrell et al. 1978).

Bussey et al. (1976) reported mean selenium concentrations of 6 to 16 ppm (dry weight) in muscle tissue of black crappie, walleye (*Stizostedion vitreum*), and largemouth bass in Lake Powell, on the Colorado River in Arizona and Utah. These concentrations would correspond to a range of some 1.2 to 3 ppm (wet weight basis), assuming 80% moisture content (Giesy and Wiener 1977). The elevated selenium levels in Lake Powell fish were considered to result from accumulation of selenium from soils and sediments in the region through the food chain. No deleterious effects of these selenium concentrations, which are similar to those seen in Belews Lake fish from Station 158, were reported.

Barnhart (1957) studied Sweitzer Lake, Colorado, where poor survival of stocked game fish was a problem. Sweitzer Lake was constructed in 1954 in an area of alkaline soils with high natural selenium content. Sweitzer Lake biota were found to contain high concentrations of selenium. It was concluded that selenium accumulation through the food chain, perhaps coupled with effects of other toxic elements (U, Zn, As), was responsible for the fish mortality observed in Sweitzer Lake.

Selenium concentrations in Belews Lake fish appear to be sufficiently elevated to reduce long-term survival and reproduction. In Belews Lake there was a tendency for selenium concentrations in the sunfishes (*Lepomis* spp.) to be higher than those in bullheads (*Ictalurus* spp.) from the same areas. Among the sunfishes, warmouth (*Lepomis gulosus*) and bluegill tended to have the highest selenium concentrations, while those of green sunfish were lower. These trends were closely correlated with the observed decline of fish poplations in the main basin of Belews Lake. Sunfishes declined most markedly, while catfishes persisted in the main lake. No such trend was noted at Station 158. Certain species, such as the catfishes, carp, and mosquitofish may be inherently less sensitive to selenium than the centrarchids.

CONCLUSIONS

Investigation of fish reproductive failure in Belews Lake indicates that the input of dissolved selenium from ash basin effluent, coupled with evaporation and retention time in the lake, has resulted in concentration of selenium in Belews Lake water. Fish in Belews Lake have accumulated unusual amounts of selenium in their tissues. Selenium accumulation, perhaps associated with other dissolved constituents which contribute to elevated conductivity, is considered to be the probable cause of reduced fish reproduction in Belews Lake. The North Carolina Department of Natural Resources and Community

Development and Duke Power Company have taken action to reduce inputs of selenium to Belews Lake.

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