Recovery of Fish Populations in Belews Lake Following Selenium Contamination

D. Hugh Barwick, *Duke Power, 13339 Hagers Ferry Road, Huntersville, NC 28078*

R. Duane Harrell, *Duke Power, 13339 Hagers Ferry Road, Huntersville, NC 28078*

Abstract: Discharge of selenium (Se)-contaminated water into Belews Lake, North Carolina, resulted in a significant decline in fish diversity and biomass. However, fish populations in this cooling reservoir slowly recovered during a 10-year period from this contamination once Se inputs into the lake ceased. During this period, Se concentrations in skeletal muscle of fish declined, number of taxa increased from 7 to 22, and estimated fish biomass increased from 5.67 to 79.66 kg/ha.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 51:209–216

Selenium is a trace element that, in low concentrations, is essential for good nutrition in fish (Sorensen 1991), but in slightly elevated concentrations (over that required for good nutrition), can result in developmental abnormalities, reproductive failure, and death in fish (e.g., Cumbie and Van Horn 1978, Garrett and Inman 1984, Gillespie and Baumann 1986, Crane et al. 1992, Lemly 1993, Saiki and Ogle 1995). Belews Lake was one of several aquatic ecosystems in the United States that was contaminated with Se in the 1970s and 1980s and the impact of this contamination has been well documented (Cumbie and Van Horn 1978; Olmsted et al. 1986; Lemly 1993, 1997; Duke Power 1996). While the toxic effects of Se on fish are generally well known, little is known regarding the recovery of fish populations in Se-contaminated ecosystems. The objective of this study was to document the recovery of fish diversity and biomass in Belews Lake following Se contamination.

Methods

Belews Lake is a 1,560-ha Duke Power reservoir in northwestern North Carolina with a mean depth of 14.6 m and an average retention time of about 1,500 days. Belews Lake was contaminated when water containing 150–200 μg/liter Se was discharged into this cooling reservoir from the ash basin at the 2,240-MW Belews Creek Steam Station (BCSS). From initial operation of BCSS in 1974 and continuing through 1984, the disposal of fly and bottom ash (which contained Se) resulting from combustion of coal at BCSS was wet-sluiced from the station into a nearby 142-ha ash pond. This ash pond reached full pool about a year after BCSS began operating and the first Se-contaminated overflow water was discharged into Belews Lake in fall 1975. This resulted in an increase in the incidence of developmental abnormalities in fish (Lemly 1993, 1997) and a significant decline in fish diversity and biomass (Cumbie and Van Horn 1978). In 1984, a dry ash handling system was implemented at BCSS and discharges of Se into Belews Lake were terminated in 1985.

To document the recovery of fish populations in Belews Lake, Se concentrations in selected fish taxa and fish diversity and biomass were monitored. Selenium concentrations were determined from 1983 through 1994 using neutron activation analysis conducted by personnel in the Department of Nuclear Engineering, North Carolina State University, as described by Finley (1985). Skeletal muscle from catfish

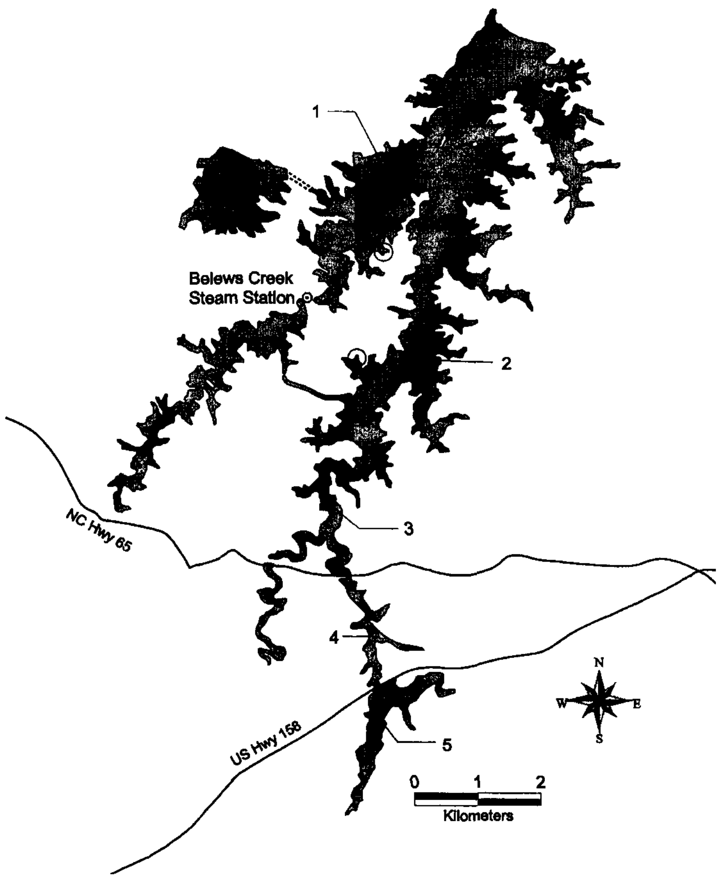

Figure 1. Fish sampling locations in Belews Lake, North Carolina. Circles indicate coves sampled with rotenone.

(*Ameiurus* spp. and *Ictalurus* spp.), green sunfish *(Lepomis cyanellus)*, and bluegills *(L. macrochirus)* were analyzed. All taxa were generally collected from 5 stations (Fig. 1) in spring and fall of most years using electrofishing or trap netting. We attempted to collect 9 fish of each taxon at each station during each sampling period for analysis, but this was not always possible. When sufficient numbers of each taxon were collected, tissue from 3 fish were combined into a composite sample and 3 composite samples per station were analyzed. When insufficient numbers of each taxon were collected, composite samples were still used, but the number of fish in a composite sample and the number of composite samples were based on the number of fish collected. Mean Se concentrations (µg/g, wet weight) for composite samples from selected fish taxa were determined.

Fish diversity and biomass were estimated from cove rotenone surveys as described by Surber (1959) and Hall (1974). Two coves (each 0.4 ha) in lower Belews Lake (Fig. 1) were sampled in July or September 1977, 1980, 1981, and 1984–1994. Fish were collected for 2 consecutive days, sorted by taxa, and weighed in aggregate. Biomass estimates (kg/ha) were calculated as mean values obtained by combining data from both coves.

Analysis of variance (Steel and Torrie 1960) was used to evaluate differences in fish diversity and biomass among years. If significant annual differences were noted, Duncan's Multiple Range Test (Steel and Torrie 1960) was used to identify annual differences. Recovery was evaluated using *t*-tests (Steel and Torrie 1960) to determine differences in fish diversity and biomass reported in 1972–1975 (before Se contamination was obvious) and in 1991–1994. All statistical comparisons were considered significant at $P < 0.05$.

Results and Discussion

Selenium Concentrations

Mean Se concentrations in fish collected from Belews Lake varied by location and year (Fig. 2). Fish from Stations 1–4 (downlake) generally exhibited similar Se concentrations that ranged up to 21.7 µg/g. Concentrations of Se in fish from Station 5 were considerably lower than concentrations noted in fish from downlake stations and rarely exceeded 3.0 µg/g. Station 5 was the only area of Belews Lake where Se concentrations in fish were not consistently elevated. Fish in this area of the reservoir also did not exhibit a decline in diversity and biomass as noted downlake (Duke Power, unpubl. data).

Mean Se concentrations in catfish, green sunfish, and bluegill were highest in fish collected from 1983 through 1987 at the downlake stations (Fig. 2). Maximum Se concentrations of 10.4, 21.7, and 16.5 µg/g were noted for these taxa, respectively. In contrast, maximum Se concentrations at Station 5 during the 1983–1987 period were 1.8, 14.9, and 3.2 µg/g for catfish, green sunfish, and bluegills, respectively. The 14.9 µg/g Se concentration for green sunfish at Station 5 greatly exceeded all other Se concentrations observed at this station. This unusually high value may have resulted from the collection of green sunfish at this station that had migrated into the area from downlake.

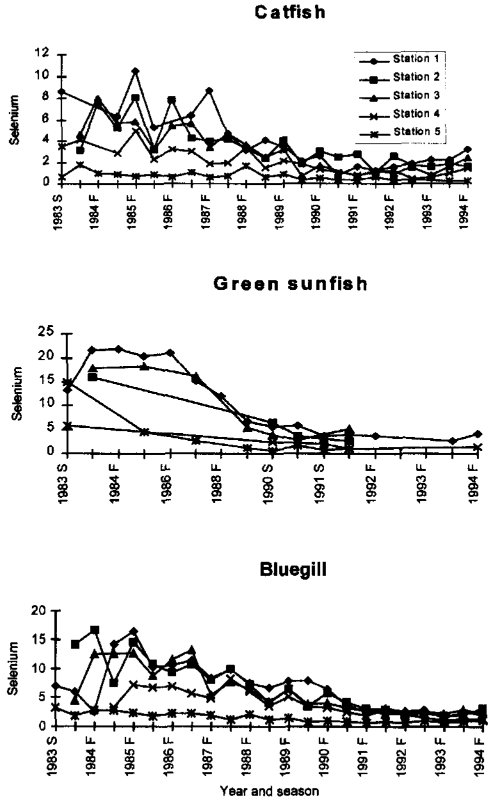

Figure 2. Mean selenium concentrations (μg/g, wet weight) in catfish, green sunfish, and bluegills collected in spring (S) and fall (F) from Belews Lake, North Carolina.

Mean Se concentrations generally began to decline in fish at the downlake stations by 1987 or 1988. By 1992, maximum Se concentrations observed at downlake stations were 2.6 μg/g for catfish, 3.8 μg/g for green sunfish, and 3.2 μg/g for bluegills. After 1992, Se concentrations in catfish, green sunfish, and bluegills at the downlake stations remained <5.0 μg/g and were only slightly higher than concentrations at Station 5.

Fish Populations

Diversity and biomass estimates of fish in Belews Lake fluctuated in cove samples collected from 1977 through 1994 (Table 1). Overall, there was a significant increase in fish diversity ($F = 4.33$, $P < 0.005$) and biomass ($F = 3.61$, $P < 0.011$) during the 1977–1994 period. However, fish diversity and biomass were similar in 1977, 1980, and 1981, and represented the lowest estimates recorded for this reservoir. During this period, diversity ranged from 7 to 13 taxa and biomass ranged from 5.67 to 15.02 kg/ha. Common carp *(Cyprinus carpio)* and channel catfish *(I. punctatus)*

Table 1. Mean annual estimates of fish biomass (kg/ha) collected from coves in Belews Lake, North Carolina. Data reported for 1972–1976 are from Van Horn (1978). Values of 0.00 indicate the presence of a taxon; however, estimated biomass was <0.005 kg/ha.

Taxa	1972	1973	1974	1975	1976	1977	1980	1981	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Blueback herring	0.19	1.13	0.14	0.04															
Alewife	0.15	0.01																	
Gizzard shad				0.07												4.56	18.50	35.58	9.22
Threadfin shad			0.00	17.18	0.05	0.10			0.82	0.42	0.13	5.22	7.69	2.14	6.16	0.85	0.66	0.30	
Satinfin shiner			0.01	0.01						0.01	0.12	0.27	2.75	0.37	0.30		0.03	0.01	
Red shiner									9.59	4.91	3.98	2.36	0.09	0.02					
Common carp	22.48	17.21	16.87	16.24	1.54	4.51	0.03	0.76	15.40	1.99	4.36	7.82	12.57	22.16	4.87	11.93	8.54	3.19	
Golden shiner	15.08	9.56	0.44	0.49	0.06		0.03		0.13	0.42	0.15	0.06	0.33	0.08	0.10				
Sandbar shiner	0.01		0.00																
Fathead minnow							2.41	6.50	6.19	3.49	0.79	0.06	0.02						
Creek chub					0.01														
Unidentified Cyprinidae								0.19				0.23							
White sucker	2.06	3.12	1.18	0.40															
Unidentified Moxostoma	0.02																		
Snail bullhead														0.18					
White catfish	0.05	0.07	0.02	0.02			0.50		0.14	0.05				0.01	0.22	1.66	0.11	1.27	0.13
Black bullhead	0.66	1.45	1.11	0.53	2.60	0.30	0.48	0.57		0.48				0.01			0.01		
Brown bullhead									0.88	1.61	1.68	0.58	1.32	1.49	1.09	1.01	0.65	0.50	
Flat bullhead	4.05	3.45	1.28	3.90	7.68	0.46			0.13	0.33		0.54	0.36	1.96	3.86	3.68	2.46	1.77	0.63
Channel catfish	0.48	1.50	2.14	1.19	0.85	8.51				1.94	5.03	2.01	1.59	2.92	1.85	5.25	5.70	5.91	6.83
Margined madtom	0.08	0.01																	
Unidentified Ictaluridae											0.00								
Redfin pickerel	0.54	0.10	0.01																
Eastern mosquitofish	0.00	0.00	0.01	0.00		0.34	1.10	1.64	1.21	0.41	0.52	0.04	0.05	0.01	0.03	0.01	0.01	0.01	0.00
White perch	0.01			0.17														0.02	
Redbreast sunfish	6.36	6.78	4.36	5.15	0.15	0.09			0.02	0.10		0.08	0.10			0.01	0.22	0.20	1.14
Green sunfish	11.18	2.86	1.92	1.10	3.06	0.15	0.62	0.32	9.59	25.95	24.26	38.06	36.85	30.33	23.51	5.67	0.78	0.44	0.42
Pumpkinseed	13.94	12.31	8.09	4.82	0.19	0.10				0.02		0.09	0.03	0.12	0.09	0.07	0.01		0.02
Warmouth	7.16	4.76	3.09	3.53	2.41	0.01	0.03		0.05	0.11	0.06	0.20	0.23	0.15	0.53	0.22	0.20	0.26	0.38
Bluegill	18.26	34.85	28.96	26.18	7.33	0.24	0.15	0.11	1.37	0.56	0.61	2.69	1.38	1.47	9.70	26.29	13.68	23.07	12.95
Redear sunfish		0.03	0.18	0.24	0.77	0.17	0.32		1.18	1.85	0.47	0.12	0.45	0.53	0.39	0.37	1.45	0.80	1.25
Lepomis hybrid									0.02	0.21	0.18	0.02	0.01	2.59	1.94	3.29	2.08	0.14	0.21
Largemouth bass	11.13	11.07	6.68	4.96	0.01								0.00	0.15	3.37	8.46	7.09	6.15	3.19
White crappie	0.83	2.47	0.20	0.25	0.14	0.04			0.20					0.14					
Black crappie	0.72	0.87	0.24	0.21	0.26				0.15					0.00	0.00	0.49		0.02	
Johnny darter			0.00	0.00															
Yellow perch			0.03	0.03								2.17	0.35	0.33	0.56	0.13	0.25	0.02	0.02
Total	115.44	113.61	76.96	86.71	27.11	15.02	5.67	10.09	47.07	44.86	42.34	62.62	66.17	67.16	58.57	73.95	62.43	79.66	36.39

composed most of the biomass (87%) in 1977, while fathead minnows *(Pimphales promelas)* and eastern mosquitofish *(Gambusia holbrooki)* composed most of the biomass in 1980 and 1981 (62% and 81%, respectively). Fathead minnows (Ogle and Knight 1989) and eastern mosquitofish (Cherry et al. 1976) are reported to be more tolerant than most fish to elevated levels of Se and, in the absence of competition and predation from other taxa, were apparently able to dominate the fish populations at that time.

By 1984, fish diversity and biomass had increased significantly over that noted in 1977–1981 and both remained similar in samples collected through 1994. Fish diversity ranged from 14 to 22 taxa and biomass ranged from 36.39 to 79.66 kg/ha. Even though diversity and biomass estimates in Belews Lake were similar after 1984, considerable change occurred in biomass composition. In 1984, red shiners *(Cyprinella lutrensis)*, common carp, fathead minnows, and green sunfish composed 87% of the biomass. Red shiners and fathead minnows had declined considerably in biomass by 1987–1988, and green sunfish then composed 61% and 56%, respectively, of the biomass. The decline in red shiner and fathead minnow biomass was probably related to the competition and predation resulting from the expansion of other fish populations in this reservoir.

Green sunfish biomass declined somewhat in 1989–1990, and continued to decline through 1994. By 1994, green sunfish composed only 1% of the biomass collected in the coves. As green sunfish biomass declined, gizzard shad *(Dorosoma cepedianum)*, channel catfish, bluegill, and largemouth bass *(Micropterus salmoides)* biomass increased. These taxa began to increase in samples collected in 1990 and composed >60% of the biomass collected in 1991–1994.

Even with the significant increase in fish diversity and biomass noted for fish in Belews Lake from 1977 through 1994, diversity and biomass estimates collected in 1991–1994 remained significantly lower (t = 3.9727, P <0.0037 and t = 2.5766, P <0.0210, respectively) than those reported in 1972–1975 by Cumbie and Van Horn (1978). A decline in fish diversity and biomass would have been expected to occur in Belews Lake from that noted in 1972–1975 (when the reservoir was recently impounded). Fish diversity and biomass generally decline in most reservoirs with age (Patriarche and Campbell 1958, Hashagen 1973, Timmons et al. 1977, Barwick et al. 1995) and Belews Lake would be expected to exhibit a similar trend. No apparent reason for the observed decline in fish biomass from 1993 to 1994 was known, but it may be possible that excellent recruitment by largemouth bass in 1991–1993 resulted in increased predation on clupeids, cyprinids, and centrarchids that was sufficient to reduce their overall biomass in samples collected in 1994. A similar situation was reported in Lake Keowee, South Carolina (Barwick and Lorenzen 1984).

Since the mid 1970s and early 1980s, numerous and significant changes have occurred in the concentrations of Se in fish, in fish diversity, and in fish biomass in Belews Lake. Concentrations of Se have declined in fish tissues, and fish diversity and biomass have increased significantly. In 1991–1994, the number of taxa and the estimated biomass of fish in this reservoir were similar to those reported for other reservoirs with similar levels of productivity in North Carolina and South Carolina

(Rodriguez and Olmsted 1993) and anglers expended about 16,406 hours fishing this reservoir from June 1993 through May 1994 (Duke Power, unpubl. data). Thus, it would appear that the fish populations in Belews Lake had generally recovered from the Se contamination.

There remains some evidence of Se contamination in this reservoir. Developmental abnormalities are still present in some larval fish (Lemly 1997), and elevated Se levels are still present in sediments and macroinvertebrates (Duke Power 1996, Lemly 1997). The impact of Se contamination on the aquatic ecosystem of Belews Lake will undoubtedly continue at some reduced level for some time. The current impact of these somewhat elevated levels of Se does not appear to have complicated the recovery of juvenile and adult fish in Belews Lake. Adequate recruitment of young fish and a substantial sport fishery are currently characteristic of the balanced, indigenous fish populations in Belews Lake.

Literature Cited

Barwick, D. H., and W. E. Lorenzen. 1984. Growth response of fish to changing environmental conditions in a South Carolina cooling reservoir. Environ. Biol. Fishes 10:271–279.

———, L. E. Miller, W. R. Geddings, and D. M. Rankin. 1995. Fish biomass and angler harvest from a South Carolina cooling reservoir. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 49:129–139.

Cherry, D. S., R. K. Guthrie, J. H. Rogers, Jr., J. Cairns, Jr., and K. L. Dickson. 1976. Response of mosquitofish *(Gambusia affinis)* to ash effluent and thermal stress. Trans. Am. Fish. Soc. 105:686–694.

Crane, M., T. Flower, D. Holmes, and S. Watson. 1992. The toxicity of selenium in experimental freshwater ponds. Arch. Environ. Contam. And Toxicol. 23:440–452.

Cumbie, P. M. and S. L. Van Horn. 1978. Selenium accumulation associated with fish mortality and reproductive failure. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 32:612–624.

Duke Power. 1996. Assessment of balanced and indigenous populations in Belews Lake. Huntersville, N.C. 80pp.

Finley, K. A. 1985. Observation of bluegills fed selenium-contaminated *Hexagenia* nymphs collected from Belews Lake, North Carolina. Bull. Environ. Contam. and Toxicol. 35: 816–825.

Garrett, G. P. and C. R. Inman. 1984. Selenium-induced changes in fish populations of a heated reservoir. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 38:291–301.

Gillespie, R. B. and P. C. Baumann. 1986. Effects of high tissue concentrations of selenium on reproduction of bluegills. Trans. Am. Fish. Soc. 115:208–213.

Hall, G. E. 1974. Sampling reservoir fish populations with rotenone. Pages 249–259 *in* R. L. Welcomme, ed. Symposium on methodology for the survey, monitoring and appraisal of fisheries resources in lakes and large rivers. Food and Agric. Org. United Nations, Rome, Italy.

Hashagen, K. A., Jr. 1973. Population structure changes and yields of fishes during the initial eight years of impoundment of a warmwater reservoir. Calif. Fish and Game 59:221–224.

Lemly, A. D. 1993. Teratogenic effects of selenium in natural populations of freshwater fish. Ecotoxicol. and Environ. Safety 26:181–204.

———. 1997. Ecosystem recovery following selenium contamination in a freshwater reservoir. Ecotoxicol. and Environ. Safety 36:275–281.

Olmsted, L. L., D. J. Degan, J. S. Carter, and P. M. Cumbie. 1986. Ash basin effluents as a concern of fisheries managers: a case history and perspective. Pages 261–269 *in* G. E. Hall and M. J. Van Den Avyle, eds. Reservoir fisheries management: strategies for the 80's. Am. Fish. Soc., Bethesda, Md.

Ogle, R. S. and A. W. Knight. 1989. Effects of elevated foodborne selenium on growth and reproduction of the fathead minnow *(Pimephales promelas)*. Arch. Environ. Contam. and Toxicol. 18:795–803.

Patriarche, M. H. and R. S. Campbell. 1958. The development of the fish population in a new flood-control reservoir in Missouri, 1948 to 1954. Trans. Am. Fish. Soc. 87:240–258.

Rodriguez, M. S. and L. L. Olmsted. 1993. Variation in fish community composition, biomass, and harvest relative to environmental parameters in reservoirs of North and South Carolina. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 47:552–570.

Saiki, M. K. and R. S. Ogle. 1995. Evidence of impaired reproduction by western mosquitofish inhabiting seleniferous agricultural drainwater. Trans. Am. Fish. Soc. 124:578–587.

Sorensen, E. M. 1991. Metal poisoning in fish. CRC Press, Inc., Boca Raton, Fla. 374pp.

Steel, R. G. D. and J. H. Torrie. 1960. Procedures of statistics. McGraw-Hill Book Co., New York, N.Y. 481pp.

Surber, E. W. 1959. Suggested standard methods of reporting fish population data from reservoirs. Proc. Annu. Conf. Southeast. Assoc. Game and Fish Comm. 13:313–325.

Timmons, T. J., W. L. Shelton, and W. D. Davies. 1977. Initial fish population changes following impoundment of West Point Reservoir, Alabama-Georgia. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 31:312–317.

Van Horn, S. L. 1978. Development of the sportfish potential of an industrial cooling lake. N. C. Wildl. Resour. Comm., Fed. Aid in Sport Fish Restor., Final Rep., Proj. F-23, Raleigh. 19pp.