Relative Abundance of Fish in 2 South Carolina Reservoirs During the First 9 Years of Pumped Storage Hydroelectric Operations

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Abstract: Relative abundance of several species of fish in the headwaters of Keowee Reservoir and in Jocassee Reservoir were estimated during the initial 9 years of operation by the Jocassee Pumped Storage Station. Several species of fish in each reservoir declined in abundance during this period, while others increased. We think the declines were related more to the chemical stabilization of these reservoirs than to pumped storage operations. The increases were related to stocking programs and natural population expansions.

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Pumped storage hydroelectric generation is a means whereby utilities use electricity generated during periods of low demand to pump water into an upper reservoir for the production of peaking hydropower. Miracle and Gardner (1980) reviewed the literature regarding the impacts of pumped storage operations on fish populations and concluded that most species are unaffected by reservoir conditions resulting from such operations. Although this may be generally true, extensive fish mortality has occurred at a few pumped storage sites (Liston et al. 1981, Richards et al. 1986). Thus, it appears that the response of fish to such operations is somewhat site specific and should be ultimately evaluated on a project by project basis. This study documents changes in the relative abundance of several species of fish in Keowee and Jocassee reservoirs during 9 years of operation by the Jocassee Pumped Storage Station (JPSS).

Methods

Keowee and Jocassee reservoirs were constructed by Duke Power Company in the upper Savannah River drainage of northwestern South Carolina. Keowee Reservoir (7,435 ha) was impounded in 1968 and reached full pool (243.8 m above

mean sea level) in 1971. This reservoir has a maximum depth of 46 m and a mean depth of 16 m. In addition to serving as the lower pool for the 610-megawatt (MW) JPSS, this reservoir is the water supply for a 140-MW hydroelectric plant, and the source of condenser cooling water for a 2,580-MW nuclear power plant.

Jocassee Reservoir (3,063 ha) was impounded in 1971 and reached full pool (338.3 m above mean sea level) in 1973. This reservoir has a maximum and mean depth of 107 m and 46 m, respectively, and serves as the upper pool for the JPSS.

Both reservoirs are warm monomictic impoundments that contain an indigenous assemblage of warmwater fish which is dominated by centrarchids. However, water temperatures and dissolved oxygen concentrations are sufficient in the hypolimnion of Jocassee Reservoir to support a "put-grow-and-take" trout (scientific names of fish mentioned in this study are listed in Table 1) fishery. This fishery is

Table 1. Common and scientific names of fish collected from Keowee and Jocassee reservoirs, South Carolina.

Common name	Scientific name
Blueback herring	*Alosa aestivalis*
Threadfin shad	*Dorosoma petenense*
Rainbow trout	*Salmo gairdneri*
Brown trout	*S. trutta*
Brook trout	*Salvelinus fontinalis*
Chain pickerel	*Esox niger*
Common carp	*Cyprinus carpio*
Golden shiner	*Notemigonus crysoleucas*
Quillback	*Carpiodes cyprinus*
White sucker	*Catostomus commersoni*
Northern hog sucker	*Hypentelium nigricans*
Spotted sucker	*Minytrema melanops*
Silver redhorse	*Moxostoma anisurum*
Smallfin redhorse	*M. robustum*
Snail bullhead	*Ictalurus brunneus*
White catfish	*I. catus*
Brown bullhead	*I. nebulosus*
Flat bullhead	*I. platycephalus*
Channel catfish	*I. punctatus*
White bass	*Morone chrysops*
White bass × striped bass hybrid	*M. chrysops* × *M. saxatilis*
Redbreast sunfish	*Lepomis auritus*
Green sunfish	*L. cyanellus*
Warmouth	*L. gulosus*
Bluegill	*L. macrochirus*
Redear sunfish	*L. microlophus*
Sunfish	*L.* spp.
Redeye bass	*Micropterus coosae*
Smallmouth bass	*M. dolomieui*
Largemouth bass	*M. salmoides*
White crappie	*Pomoxis annularis*
Black crappie	*P. nigromaculatus*
Yellow perch	*Perca flavescens*
Walleye	*Stizostedion vitreum vitreum*

Table 2. Total hours of operation for all four units of the Jocassee Pumped Storage Station.

Year	Mode of operation	
	Pumping	Generation
1973	25	7
1974	342	343
1975	822	771
1976	986	889
1977	896	812
1978	523	516
1979	877	870
1980	1297	1070
1981	1284	1053
1982	1170	958

maintained through annual stockings of both rainbow trout and brown trout by the South Carolina Wildlife and Marine Resources Department.

Pumped storage operations at JPSS began in December 1973 and have varied annually thereafter (Table 2). During generation which occurs primarily on weekdays, water is discharged (maximum flows of 818 m^3/sec) from Jocassee Reservoir at a depth of 13.1–20.4 m. Pumping, which occurs primarily at night and on weekends, withdraws (maximum flows of 773 m^3/sec) water from Keowee Reservoir at a depth of 12.8–20.1 m. Pumped storage operations have generally resulted in maximum weekly water level fluctuations of about 1 m in Keowee Reservoir and 3 m in Jocassee Reservoir.

From 1973 through 1982, multifilament nylon gill nets, 45.5 × 1.8 m, containing 3 3-m panels each of 5 mesh sizes (25, 38, 51, 63, and 75 mm, bar mesh) were set horizontally on the bottom at depths ranging from 2.9 m to 20.0 m and fished overnight at 10 stations in the headwaters of Keowee Reservoir (that area extending 5 km downstream from Jocassee Dam) during January, February, April, May, July, August, October, and November. Nets identical to those used in Keowee Reservoir were set (depths ranging from 3.0 m to 25.5 m) overnight for 2 consecutive days at 5 stations in Jocassee Reservoir during January, March, May, July, and November 1974–1982. Total numbers and weights (kg) of all fish caught were recorded for each sampling period. Estimates of relative fish abundance in Keowee and Jocassee reservoirs were based on a standard catch per unit of effort derived from the total number of gill-net sets per year.

Annual fishing pressure (hours) and catch rates (number/hour and kg/hour) for the primary sport fish caught by fishermen in the headwaters of Keowee Reservoir and in Jocassee Reservoir were estimated from 1974 through 1982 (except in Keowee Reservoir for 1976) by roving creel surveys similar to that described by Malvestuto et al. (1978). These surveys were designed and the data processed by the Southeastern Cooperative Fish and Game Statistics Project, Institute of Statistics, North Carolina State University.

The gill-net data and the Keowee Reservoir creel data presented in this study

were collected by DHB while he was employed by the U.S. Fish and Wildlife Service and by WRG (under contract to the U.S. Fish and Wildlife Service), respectively. These data were provided to us for publication by James P. Clugston (U.S. Fish and Wildlife Service) and we thank him for his assistance.

Results

Keowee Reservoir

Gill-net catches of fish from Keowee Reservoir varied annually from 1973 through 1982 (Table 3). Total numbers and biomass of fish caught were highest in 1973 and 1974, then declined. The total number of fish caught annually continued to decline from 1975 through 1980, but a slight increase was noted in 1981 and 1982. Total biomass remained somewhat consistent at a low level from 1975 through 1982.

The most obvious declines in fish abundance were noted for chain pickerel, common carp, quillback, silver redhorse, smallfin redhorse, brown bullheads, flat bullheads, bluegill, largemouth bass, and black crappies. Chain pickerel, brown bullheads, and bluegill were only moderately abundant during 1973 and 1974 and they were absent from catches after 1977. Common carp, quillback, silver redhorse, smallfin redhorse, and flat bullheads were abundant initially, then declined. Largemouth bass and black crappie abundance generally increased from 1973 through 1975 or 1976, then declined and remained low from 1979 through 1982.

White catfish, white bass, and redeye bass increased in abundance during the study. Their numbers were low initially, then increased and were generally highest in 1980–1982. Yellow perch abundance was low and remained low during this study.

The number of angler hours of fishing pressure expended in the headwaters of Keowee Reservoir ranged from 2,465 to 7,462 in 1974–1982 (Table 4). Pressure was low initially, increased through 1977–1978, then declined and remained consistent thereafter. Only 3 fish taxa—sunfish, largemouth bass, and black crappie—were consistently caught by anglers. Sunfish catch rates were highest in 1974, then declined and remained low from 1975 through 1982 (Table 4). Largemouth bass catch rates varied annually. Catches were lowest in 1974 and 1975, then increased and were generally similar from 1977 through 1982. Black crappie catch rates were low in 1974, highest in 1975–1976, then declined and were lowest in 1979–1982.

Jocassee Reservoir

Gill-net catches of fish from Jocassee Reservoir (Table 5) also fluctuated annually. Total numbers of fish caught were highest in 1974, then declined through 1976. From 1976 through 1980, numbers of fish caught changed little, but increased slightly in 1981–1982. Total biomass of fish caught declined from 1974 to 1976, then increased progressively through 1982.

Overall declines in abundance were noted for rainbow trout, chain pickerel,

Table 3. Total numbers (*N*) and biomass (kg) of fish collected per 50 gill-net sets in Keowee Reservoir, South Carolina.

	Years																			
	1973		1974		1975		1976		1977		1978		1979		1980		1981		1982	
Species	*N*	kg	*N*	kg	*N*	kg	*N*	kg	*N*	kg	*N*	kg	*N*	kg	*N*	kg	*N*	kg	*N*	kg
Chain pickerel	7	6.0	3	3.1	1	1.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common carp	45	19.1	35	14.5	12	5.3	21	9.8	27	12.7	35	19.0	30	17.1	27	13.8	29	17.1	19	11.9
Quillback	56	47.1	75	65.7	25	24.1	26	20.4	12	12.2	18	21.0	1	0.7	2	2.7	12	13.6	11	14.0
Silver redhorse	123	52.0	143	60.0	60	26.5	59	28.1	39	20.6	56	34.1	39	23.5	21	13.2	36	23.4	44	29.0
Smallfin redhorse	9	3.5	4	1.7	1	0.8	1	0.4	1	0.5	1	0.6	0	0	1	0.3	2	0.9	3	1.2
White catfish	0	0	0	0	1	0.1	1	0.1	3	0.6	8	1.3	6	0.8	8	1.3	16	4.0	13	3.2
Brown bullhead	4	1.2	1	0.1	3	0.6	1	0.3	0	0	0	0	0	0	0	0	0	0	0	0
Flat bullhead	44	5.5	56	7.3	48	6.2	32	3.8	43	4.6	28	2.7	32	3.1	28	2.5	26	2.6	32	3.7
White bass	0	0	0	0	1	0.1	1	0.2	2	0.6	14	9.4	12	5.9	4	3.2	6	5.1	9	9.8
Bluegill	7	0.9	4	0.8	1	0.1	1	0.1	0	0	0	0	0	0	0	0	0	0	0	0
Redeye bass	1	0.1	1	0.1	0	0	1	0.2	1	0.2	3	0.4	2	1.4	5	1.1	11	2.4	12	2.6
Largemouth bass	7	3.8	10	4.6	10	4.2	11	5.6	6	1.7	6	1.5	3	2.8	4	1.9	4	1.9	4	2.8
Black crappie	22	1.8	33	3.2	59	6.1	41	4.4	48	4.4	27	3.4	8	0.9	8	0.8	8	1.1	4	0.5
Yellow perch	4	0.6	4	0.6	2	0.3	3	0.3	1	0.1	1	0.3	4	0.6	1	0.3	1	0.4	1	0.2
Others[a]	6	1.6	3	1.9	5	7.1	4	1.1	3	1.2	6	6.4	2	3.1	4	6.1	4	2.5	8	3.2
Total	335	143.2	372	163.6	229	82.6	203	74.8	186	59.4	203	100.1	139	59.9	113	47.2	155	75.0	160	82.1

[a]Includes blueback herring, rainbow trout, brown trout, golden shiner, northern hog sucker, spotted sucker, snail bullhead, channel catfish, warmouth, redear sunfish, white crappie, and walleye.

Table 4. Estimates of fishing pressure (hour) and of catch rates (*N*/hour and kg/hour) for sport fish in the headwaters of Keowee Reservoir, South Carolina.

		Taxa and catch rates					
		Sunfish		Largemouth bass		Black crappie	
Year[a]	Pressure	*N*/hour	kg/hour	*N*/hour	kg/hour	*N*/hour	kg/hour
1974	2,465	0.35	0.04	0.12	0.05	0.10	0.02
1975	2,526	0.08	0.01	0.04	0.03	0.25	0.07
1977	7,462	0.19	0.05	0.23	0.16	0.19	0.04
1978	7,076	0.10	0.02	0.26	0.20	0.11	0.04
1979	5,357	0.07	0.01	0.22	0.17	0.09	0.03
1980	4,750	0.13	0.02	0.14	0.10	0.06	0.01
1981	4,565	0.13	0.02	0.19	0.10	0.08	0.01
1982	5,377	0	0	0.32	0.27	0.09	0.02

[a]No data available for 1976.

common carp, quillback, silver redhorse, brown bullheads, flat bullheads, bluegill, largemouth bass, and black crappies. During this period, brown trout, white catfish, white bass, redeye bass, and smallmouth bass increased in abundance. Yellow perch abundance increased through 1977, then declined.

From 1974 through 1982, fishing pressure in Jocassee Reservoir fluctuated annually (Table 6). Pressure was lowest in 1974, increased in 1975, and remained relatively constant through 1982. Rainbow trout, brown trout, sunfish, largemouth bass, and black crappies dominated the creel. Rainbow trout and sunfish catch rates were highest in 1974, then declined and were generally lowest in 1977–1982. Catches of brown trout and black crappies were low initially. However, brown trout catches increased gradually from 1974 through 1979 and then remained high and relatively stable from 1979 through 1982. Black crappie catches increased from 1974 to 1976, then declined and were consistently low in 1979–1982. Largemouth bass catch rates were consistently high from 1974 through 1978. After 1978, they declined and remained low through 1982.

Discussion

While the gill-net and creel data collected from Keowee and Jocassee reservoirs are not suitable for quantitative computations of fish abundance, they do provide a basis for some general conclusions regarding the relative abundance of several species of fish in these reservoirs. In general, chain pickerel, common carp, quillback, silver redhorse, smallfin redhorse, brown bullheads, flat bullheads, bluegill, largemouth bass, and black crappies were most abundant in both reservoirs during the early years of this study. Their abundance then declined (prior to maximum pumped storage operations) and in most cases stabilized at a low level and remained at this level for the duration of the study. These changes in abundance are consistent with those observed in other reservoirs (Patriarche and Campbell 1958, Hashagen 1973, Timmons et al. 1977) and are apparently related to the chemical stabilization or the aging process that occurs in recently impounded reservoirs.

Table 5. Total numbers (N) and biomass (kg) of fish collected per 50 gill-net sets in Jocassee Reservoir, South Carolina.

	Years																	
	1974		1975		1976		1977		1978		1979		1980		1981		1982	
Species	N	kg	N	kg	N	kg	N	kg	N	kg	N	kg	N	kg	N	kg	N	kg
Rainbow trout	34	31.4	13	8.7	6	5.5	10	2.4	10	1.9	3	2.9	11	1.4	17	2.4	11	1.4
Brown trout	32	27.2	63	97.0	75	93.1	83	101.9	87	117.1	84	148.1	100	181.6	192	225.3	146	256.0
Chain pickerel	6	3.2	11	10.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common carp	190	161.2	21	23.7	20	17.7	37	28.6	12	8.6	32	23.1	24	21.5	17	16.3	13	13.1
Quillback	46	40.6	20	18.8	20	19.8	9	9.6	32	36.1	19	22.6	13	14.5	6	7.4	14	16.3
Silver redhorse	12	6.6	8	5.6	6	3.9	7	5.6	5	3.9	2	1.8	10	8.3	4	4.2	3	3.3
White catfish	0	0	0	0	0	0	0	0	1	0.1	1	0.3	3	0.7	3	0.8	3	0.6
Brown bullhead	6	2.0	3	0.7	4	1.5	4	1.5	6	1.8	1	0.3	3	0.9	2	0.7	0	0
Flat bullhead	76	9.6	24	4.2	17	2.8	6	0.8	13	1.8	5	0.5	6	1.1	18	2.3	31	4.6
White bass	0	0	1	0.3	1	0.3	1	0.2	1	0.9	14	7.6	16	13.2	14	13.1	7	10.0
Bluegill	28	3.4	5	1.3	4	0.8	0	0	0	0	0	0	0	0	0	0	0	0
Redeye bass	0	0	1	0.1	0	0	2	0.4	4	1.2	2	0.6	5	2.0	7	2.4	10	3.0
Smallmouth bass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	2.6	9	3.3
Largemouth bass	62	27.8	48	28.5	27	12.7	21	13.0	13	6.3	7	3.7	6	2.0	7	3.8	8	4.9
Black crappie	104	9.6	61	13.4	8	2.5	4	0.8	0	0	1	0.6	0	0	0	0	0	0
Yellow perch	6	1.4	4	0.6	11	2.4	24	7.4	8	2.1	12	4.1	9	2.3	5	2.6	2	1.1
Others[a]	16	8.8	8	3.7	2	0.8	5	1.2	2	1.2	2	0.3	2	0.1	6	3.3	8	2.0
Total	618	332.8	291	217.1	201	163.8	213	173.4	194	183.0	185	216.5	208	249.6	309	287.2	265	319.6

[a]Includes blueback herring, brook trout, golden shiner, white sucker, spotted sucker, smallfin redhorse, snail bullhead, *Morone* hybrid, redbreast sunfish, green sunfish, warmouth, and walleye.

Table 6. Estimates of fishing pressure (hour) and of catch rates (*N*/hour and kg/hour) for sport fish in Jocassee Reservoir, South Carolina.

		Taxa and catch rates									
		Rainbow trout		Brown trout		Sunfish		Largemouth bass		Black crappie	
Year	Pressure	*N*/hour	kg/hour	*N*/hour	kg/hour	*N*/hour	kg/hour	*N*/hour	kg/hour	*N*/hour	kg/hour
1974	28,489	0.10	0.01	0	0	1.06	0.17	0.32	0.12	0.02	0.01
1975	53,637	0.12	0.02	0	0	0.17	0.03	0.25	0.13	0.14	0.04
1976	63,251	0.03	0.03	0.01	0.01	0.13	0.03	0.27	0.15	0.38	0.12
1977	69,779	T[a]	0.01	0.03	0.04	0.02	T	0.37	0.21	0.26	0.06
1978	63,719	T	T	0.03	0.05	0.02	T	0.32	0.16	0.15	0.04
1979	75,715	T	T	0.08	0.12	0.01	T	0.18	0.10	0.04	0.01
1980	58,361	T	T	0.07	0.14	T	T	0.10	0.07	0.02	0.01
1981	70,358	0.01	0.01	0.09	0.12	0.01	T	0.13	0.08	0.02	T
1982	62,298	T	T	0.08	0.11	0.02	T	0.18	0.12	0.02	0.01

[a]T = Trace (<0.005)

Keowee Reservoir reached full pool in 1971 and Jocassee Reservoir in 1973. Thus, both reservoirs were recently impounded when this study began. Jenkins (1968) has identified reservoir age as being an important variable in predicting fish standing crop. He found that fish standing crop was negatively correlated with reservoir age during the first few years of impoundment. This correlation results because recently impounded reservoirs have higher levels of nutrients and production than do reservoirs that have been impounded for several years. We feel that Keowee and Jocassee reservoirs were undergoing this same aging process and that during the initial years of sampling, fish populations were high. Then during the ensuing years, nutrient levels declined and stabilized (Duke Power Company, unpubl. data) and the abundance of some species of fish apparently responded likewise. Declining growth rates of bluegill, largemouth bass, and black crappies in Keowee Reservoir from 1968 through 1977 (Barwick and Lorenzen 1984) would also indicate that this aging process was occurring in Keowee Reservoir.

Even though rainbow trout do not reproduce and are stocked annually in Jocassee Reservoir, declines in their abundance may have also been related to chemical stabilization of reservoir conditions. Rainbow trout were first stocked in 1972 and the initial results of these plantings were promising. Gill-net catches in 1974 indicated that these fish were surviving and growing well. However, survival declined subsequently. Barwick and Geddings (1985) reported that survival of planted rainbow trout in Jocassee Reservoir was low in 1981 because the stocked fish were apparently not large enough to prey on the size of threadfin shad available. It is not known if this was the case in 1972–1974. But, it is possible that zooplankton and aquatic insect populations were sufficient at that time to provide an alternative prey for these fish until they could reach a size large enough to eat threadfin shad. Regardless of the reason, rainbow trout survival was obviously higher from 1972 to 1974 than in 1981 when few fish survived longer than 3 months.

Not all species of fish caught in Keowee and Jocassee reservoirs declined in abundance during this study. White catfish, white bass, and redeye bass in both

reservoirs and brown trout and smallmouth bass in Jocassee Reservoir increased in abundance. White catfish and redeye bass are indigenous to these reservoirs, but their abundance was so low initially that few were caught. In the latter years of the study, their populations had expanded and a few were being caught. Although white bass are abundant in other Savannah River reservoirs, they were not caught in Keowee and Jocassee reservoirs until 1975. Since then their abundance has increased considerably. We suspect that they were introduced by fishermen. Brown trout and smallmouth bass were stocked in Jocassee Reservoir by the South Carolina Wildlife and Marine Resources Department in 1973 and 1980, respectively. Annual brown trout abundance is reflective of stocking rates and growth, while smallmouth bass are expanding naturally.

Pumped storage operations have undoubtedly affected certain aspects of the ecology of Keowee and Jocassee reservoirs. For example, pumped storage operations resulted in increased water level fluctuations in both reservoirs. However, these fluctuations were less than that (4 m) reported by Estes (1971) and Bennett (1975) which did not adversely affect centrarchid spawning in Leesville Lake, Virginia. Plant operation also altered summer stratification in Jocassee Reservoir and this resulted in a decline in trout habitat (water with temperatures $<20°$ C and dissolved oxygen concentrations >5 mg/l) during summer (Oliver et al. 1977, Oliver and Hudson 1980). In addition, pumped storage operations were responsible for the entrainment of larval fish (Prince and Mengel 1980). Sunfish were the predominant taxa entrained and most were entrained during pumping. Entrainment of adult fish has not been studied at this site, but there is no evidence to suggest that this is a serious problem. No major fish kills have been observed or reported near the JPSS.

In summary, it appears that pumped storage operations have not seriously impacted the fishery resources of Keowee or Jocassee reservoirs. These reservoirs continue to support viable fisheries with catch rates that are similar to those reported from other southern reservoirs with similar levels of fertility (Jenkins 1968).

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