Fish Biomass and Angler Harvest from a South Carolina Cooling Reservoir

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Abstract: Fish biomass and angler harvest data were collected from Keowee Reservoir during a period when thermal characteristics of this reservoir were significantly altered by operation of a large steam-electric power plant. Plant operation increased the heat load of the reservoir and depressed the depth of the thermocline. During the 22-year sampling period, fish biomass (primarily for non-sportfish taxa) declined, fishing effort increased, and angler harvest rates remained unchanged.

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Thermal characteristics of cooling reservoirs are altered by dissipation of waste heat from steam-electric generating stations. Because water temperature influences many of the life processes of fish, significant alterations in thermal regimes of cooling reservoirs may have significant long-term impacts on fishery resources and recreational fishing opportunities associated with these special-use reservoirs. Numerous studies (e.g., Gibbons et al. 1972, Benda and Proffitt 1974, Siler and Clugston 1975, Tranquilli et al. 1981, Ryan et al. 1986) have been conducted regarding the impact of waste heat on the aquatic environment, but few have focused on long-term impacts. In this paper, we discuss long-term responses of fish biomass and angler harvest to thermal alterations in Keowee Reservoir, a South Carolina cooling impoundment.

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Methods

Keowee Reservoir is a 7,435-ha impoundment constructed by Duke Power Company in the upper Savannah River drainage of northwestern South Carolina. This reservoir was impounded in 1968 and reached full pool (243.8 m above mean sea level) in 1971. It has a maximum depth of 46 m, a mean depth of 16 m, and is used primarily as a source of condenser cooling water for Oconee Nuclear Station (ONS). This reservoir also supplies water for Jocassee Pumped-Storage Hydroelectric Station (610 MW) and Keowee Hydroelectric Station (140 MW). Pumped-storage operations pump water from Keowee Reservoir at night and on weekends into Jocassee Reservoir for later use in the production of peaking hydropower. Pumped-storage and conventional hydropower operations do impact thermal regimes in Keowee Reservoir, but their impact is minor when compared to the impact of ONS.

Commercial production of electricity at ONS (2,580 MW) began in July 1973 and this station has generally operated at >50% capacity since 1975 (Duke Power Co. 1995). Operation of ONS significantly altered thermal characteristics of Keowee Reservoir by creating a surface oriented, heated-water plume, by increasing the heat load of the reservoir, and by increasing the depth of the thermocline (Oliver and Hudson 1987, Duke Power Co. 1995). The heated-water plume was generally evident 6–10 km from ONS's outfall. Maximum surface water temperatures of 32–33 C (27–29 C before ONS was operational) were noted after ONS became operational and the heat load to the reservoir was increased by about 33%. Due to a skimmer wall intake that allowed withdrawal of cooling water from a depth of 20–27 m, ONS operations resulted in a depression of the thermocline from a depth of 5–15 m to about 27 m. Associated with depression of the thermocline was an increase in dissolved oxygen concentrations at greater depths. Operation of ONS resulted in dissolved oxygen concentrations of 4–6 mg/liter to depths >20 m in late summer and early fall.

August estimates of fish biomass were obtained annually from 2 coves (Fig. 1) sampled with rotenone in 1972–1981, 1986–1990, and 1993 using techniques described by Barwick (1984). The only exception was that fish collected on the second day in 1986–1993 were sorted by taxa into length groups and counted, but weights were extrapolated from weights for similar-size fish obtained the first day. National Biological Survey personnel collected cove data in 1972–1981, while South Carolina Department of Natural Resources and Duke Power Company personnel collected these data in 1986–1993. Generally, the same coves (ranging in size from 0.5 to 1.1 ha, depending on reservoir elevation) were sampled each year. Shoreline development in southern Keowee Reservoir resulted in selection of an adjacent cove for sampling in 1993.

Fishing effort and angler harvest estimates were obtained from roving creel

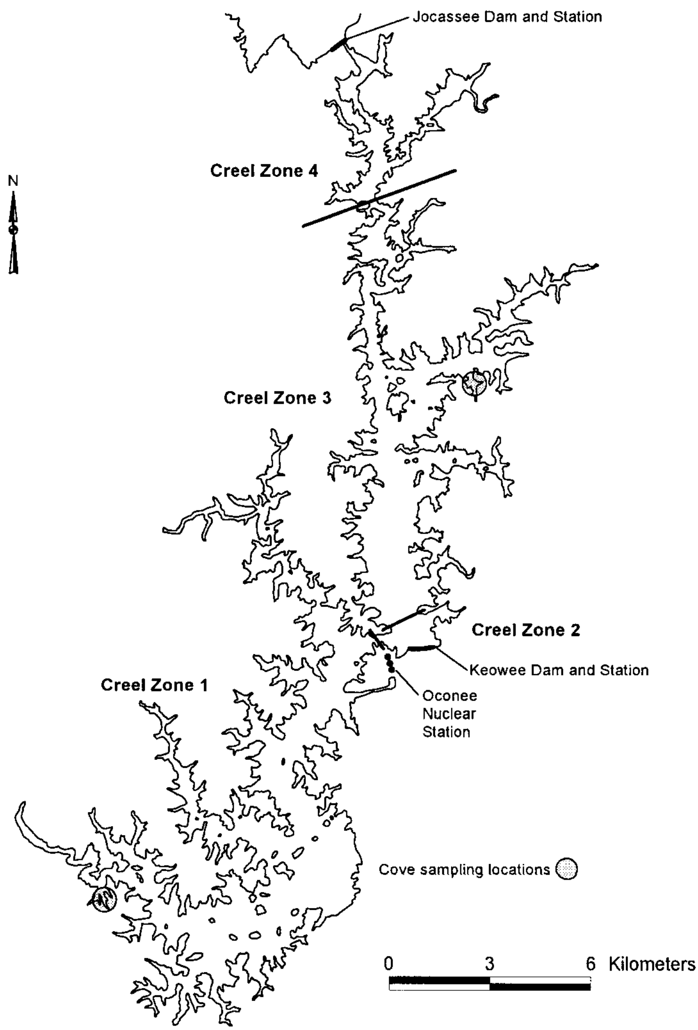

Figure 1. Sampling locations for fishery surveys of Keowee Reservoir, South Carolina.

surveys conducted annually on Keowee Reservoir in 1974–1982, 1985, 1987, 1990, 1991, and 1993. These surveys used a stratified 2-stage design similar to that described by Malvestuto (1983). Survey design in 1977–1993 produced estimates of effort and harvest from 4 zones within the reservoir (Fig. 1).

Fish biomass data were initially analyzed using t (equal variances) and t' (unequal variances) tests (Steel and Torrie 1960) to determine if area differences existed. Depending on these results, trends in biomass were analyzed independently by area (where significant area differences were noted) or data from both coves were pooled and analyzed. Regression analyses (Neter and Wasserman 1974) were used to evaluate trends in biomass. Trends (either increasing or decreasing) were noted when a significant statistical relation was identified between fish biomass (dependent variable) and years (independent variable). Trend analyses were also used to evaluate angler effort and harvest data. In these analyses, the significance of the statistical relations between effort, harvest (*N*/hour and kg/hour), and mean weight (dependent variables), and years (independent variable) were evaluated. Analysis of variance procedures and Duncan's multiple range test (Steel and Torrie 1960) were used to determine if zone differences existed for effort (hours/ha) and harvest (*N*/ha and kg/ha) data. Statistical comparisons were considered significant at $P < 0.05$.

Results and Discussion

Fish Biomass

Thirty-one fish taxa were collected from coves sampled in Keowee Reservoir, but 17 composed most (>97%) of the biomass (Table 1). During the 1972–1993 sampling period, annual total fish biomass ranged from 11.98 to 133.80 kg/ha uplake and from 29.48 to 112.07 kg/ha downlake. However, no significant area differences were noted in total fish biomass. Furthermore, no significant area differences were noted in biomass estimates for threadfin shad (*Dorosoma petenense*), common carp (*Cyprinus carpio*), brassy jumprock (*Scartomyzon* sp.), white catfish (*Ameiurus catus*), brown bullhead (*A. nebulosus*), channel catfish (*Ictalurus punctatus*), redbreast sunfish (*Lepomis auritus*), warmouth (*L. gulosus*), redeye bass (*Micropterus coosae*), spotted bass (*M. punctulatus*), largemouth bass (*M. salmoides*), and black crappie (*Pomoxis nigromaculatus*). Biomass estimates for the v-lip redhorse (*Moxostoma collapsum*) and the flat bullhead (*A. platycephalus*) were significantly higher uplake than downlake, while biomass estimates for bluegill (*L. macrochirus*) and yellow perch (*Perca flavescens*) were significantly higher downlake than uplake.

Overall, mean annual estimates of total fish biomass declined significantly in Keowee Reservoir from 1972 through 1993 (Table 1). This decline was primarily due to significant declines in the biomass estimates of common carp, v-lip redhorse (uplake only), brown bullhead, flat bullhead (uplake only), warmouth, bluegill (uplake only), and yellow perch. In contrast, channel catfish, spotted bass, and redeye bass biomass estimates increased significantly during the 1972–1993 period.

Because little biomass data were collected from Keowee Reservoir prior to operation of ONS, it was difficult to determine if ONS was responsible for the significant declines noted in fish biomass. Jenkins (1977) offered an alternative to standard impact assessment using before and after comparisons. He suggested that environmental impact can sometimes be evaluated by comparing observed and predicted estimates of fish biomass. Predicted fish biomass for Keowee Reservoir was calculated to be 87.84 kg/ha using the model suggested

Table 1. Mean estimated biomass of fish (kg/ha) collected from 2 coves sampled in Keowee Reservoir, South Carolina. T = trace (<0.005 kg/ha).

Taxa	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1986	1987	1988	1989	1990	1993
Threadfin shad	0.00	0.00	5.33	9.32	2.53	3.11	5.47	1.52	5.76	8.35	0.51	0.16	4.74	0.73	3.66	0.02
Common carp	81.77	25.18	40.35	18.38	30.40	36.62	29.72	29.81	38.10	40.07	54.87	14.72	15.92	9.97	8.31	9.78
V-lip redhorse	5.15	0.79	2.43	2.50	2.79	2.67	0.69	0.30	1.05	1.77	2.82	0.65	2.00	0.10	0.00	2.26
Brassy jumprock	0.00	0.17	0.00	0.16	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.17	0.00	0.01	0.00	1.16
White catfish	0.00	0.00	0.00	0.00	0.00	0.40	0.17	2.41	0.67	0.04	0.68	0.12	0.02	0.62	0.58	0.01
Brown bullhead	4.29	1.90	1.42	0.50	2.18	0.70	0.00	0.51	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flat bullhead	2.69	1.79	1.37	1.00	1.91	2.04	1.60	1.83	1.05	1.74	2.15	0.44	0.59	0.59	0.40	1.16
Channel catfish	0.00	0.00	0.18	0.00	0.00	0.00	0.11	0.02	0.04	0.16	0.13	1.11	0.72	1.54	1.08	6.05
Redbreast sunfish	1.43	0.69	0.92	1.47	1.37	1.51	2.23	1.93	2.21	2.35	1.62	0.90	0.70	0.95	2.68	6.16
Green sunfish	0.17	0.15	0.22	0.44	0.36	0.82	0.84	0.57	0.85	0.71	0.60	0.26	0.10	0.22	0.63	1.98
Warmouth	2.21	2.02	2.56	2.16	0.90	0.91	0.61	0.60	0.40	0.44	1.73	0.18	0.18	0.32	0.58	0.87
Bluegill	4.41	7.54	17.17	9.37	6.73	7.57	6.59	6.48	9.94	9.55	5.93	4.13	2.82	4.33	6.50	8.53
Redeye bass	0.01	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.02	0.13	0.01	0.31	0.58
Spotted bass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.26	0.14	0.29
Largemouth bass	3.92	4.65	4.88	5.29	1.61	2.61	2.14	3.68	3.24	3.90	11.92	2.21	4.14	1.86	2.83	5.16
Black crappie	0.11	2.00	7.75	0.23	0.10	3.06	0.05	1.46	0.64	0.07	T	0.03	0.00	0.16	T	0.00
Yellow perch	0.60	1.47	3.82	1.31	2.26	1.88	1.84	0.69	1.03	1.35	0.42	0.11	0.20	0.07	0.07	0.17
Others	0.15	0.16	0.73	0.52	0.55	0.86	0.72	0.57	1.50	1.40	1.35	0.38	0.70	0.59	0.40	0.79
Total	106.91	48.51	89.25	52.65	53.69	64.76	52.78	52.98	66.60	71.90	85.26	25.59	33.48	22.33	28.17	44.97

by Ploskey et al. (1986). Their model used reservoir surface area, shoreline development, and total dissolved solids as predictors. Predicted biomass was higher than the observed mean biomass (56.24 kg/ha) from Keowee Reservoir during the 1972–1993 sampling period and considerably higher than the mean biomass (39.97 kg/ha) estimated in 1986–1993.

The response of fish to depression of the thermocline may partially explain the differences noted between the observed and predicted biomass estimates. Barwick (1984) reported fish biomass estimates collected from coves sampled in Keowee Reservoir were significantly higher in May (129.7 kg/ha) than in August (53.4 kg/ha). He thought considerable numbers of fish (which included those commonly found in both spring and summer samples) had migrated to depths deeper than the coves (maximum depth of 6.7 m) sampled in August. This movement of fish from the coves was also evident in 1986, 1989, and 1990 (only years during the 1986–1993 period when spring cove samples were collected) when mean biomass estimates were 94.7 kg/ha and 45.2 kg/ha in May and August, respectively (Duke Power Co., unpubl. data). Thus, August sampling may have significantly underestimated fish biomass in Keowee Reservoir and spring biomass estimates may be more representative of fish biomass for this reservoir. If this is true, impact is not suggested since spring biomass estimates were similar to those predicted for this reservoir.

While declines noted in fish biomass may have been somewhat confounded by ONS's depression of the thermocline and possible movement of fish into deeper water, the decline in fish biomass from 1972 to 1993 was similar to that observed for many other reservoirs (Patriarche and Campbell 1958, Hashagen 1973, Timmons et al. 1977). In 1972, Keowee Reservoir was recently impounded (reached full pool in March 1971), and recently impounded reservoirs are generally more productive than older reservoirs (e.g., Wright 1967, Kimmel and Groeger 1986). The high biological productivity associated with recently impounded reservoirs generally results in elevated fish biomass initially that eventually declines in subsequent years (Jenkins 1967). This initial elevation in fish biomass was thought by Jenkins (1977) to be related primarily to elevated nutrients during reservoir filling, but other factors may also be involved. Cherry and Guthrie (1975) reported that detritus is abundant in most recently impounded reservoirs and some fish develop a competitive advantage by utilizing it as a food source. Thus, omnivorous taxa might be expected to thrive initially in a recently impounded reservoir, only to decline in abundance once this food source is exhausted. This may explain the declines noted in biomass for several omnivorous taxa (e.g., brown bullhead and flat bullhead).

After Keowee Reservoir reached full pool, some taxa also lost critical spawning habitat. This was especially true for common carp. Without recently inundated vegetation on which to deposit their eggs (Carlander 1969, Scott and Crossman 1973), recruitment for this taxon was poor. Inasmuch as common carp is a long-lived fish and was successful in reproducing during the filling years of Keowee Reservoir, this taxon was able to dominate biomass estimates for some time. However, poor recruitment and natural mortality eventually resulted in a significant decline in common carp biomass.

Angler Effort and Harvest

Effort and harvest by anglers fishing Keowee Reservoir varied annually during 1974–1993 (Fig. 2). Total effort was low initially, ranging from 58,963 to 63,405 hours in 1974–1976. Effort increased in 1977 and remained above 108,000 hours thereafter. Maximum fishing effort was estimated to be 241,268 hours (32.4 hours/ha) in 1991. Overall, a significant increase was noted in fishing effort expended by anglers fishing Keowee Reservoir during the study period.

Largemouth bass were the most fished for taxon in Keowee Reservoir. Sunfish (*Lepomis* spp.) and crappies (*Pomoxis* spp.) were the only other taxa that contributed substantially to the sport fishery of this reservoir. A significant increase in fishing effort was noted for anglers fishing for largemouth bass, but no significant changes were noted in harvest rates (*N*/hour and kg/hour) or in the mean weight of harvested fish (Fig. 2). A significant decline was noted in effort expended by sunfish anglers and in mean weight of sunfish harvested (Fig. 2). However, sunfish harvest rates (*N*/hour and kg/hour) were not significantly different in 1974–1993. The decline in the mean weight of sunfish harvested was apparently related to a decline in sunfish growth rates (Barwick and Lorenzen 1984). No significant changes were noted in effort, harvest rates, and mean weight of crappies harvested annually from Keowee Reservoir in 1974–1993 (Fig. 2).

Creel Zone 2 was heavily utilized by anglers fishing Keowee Reservoir (Fig. 3). Fishing effort and harvest of sunfish, largemouth bass, and crappie were significantly higher in Zone 2 than in Zones 1, 3, and 4. No significant differences in fishing effort and harvest were noted for these 3 taxa in Zones 1, 3, and 4.

Generally, reservoir-wide angler effort and harvest of fish from Keowee Reservoir did not appear to be negatively impacted by ONS's operations. Overall, fishing effort increased and harvest remained generally unchanged during the study period. Angler effort and harvest for Keowee Reservoir was similar to that reported for some (but not all) nearby Savannah River reservoirs (Table 2).

Elevated effort and harvest of fish in Zone 2 in Keowee Reservoir appeared to result from the attraction of fish to ONS's heated-water discharge in winter. Such an attraction is common for steam-electric power plants (e.g., Benda and Proffitt 1974, Minns et al. 1978, Ross and Winter 1981, and Tranquilli et al. 1981).

Summary and Management Implications

In general, altered thermal regimes resulting from the operation of ONS appeared to have little long-term impact on sportfish populations, fishing effort,

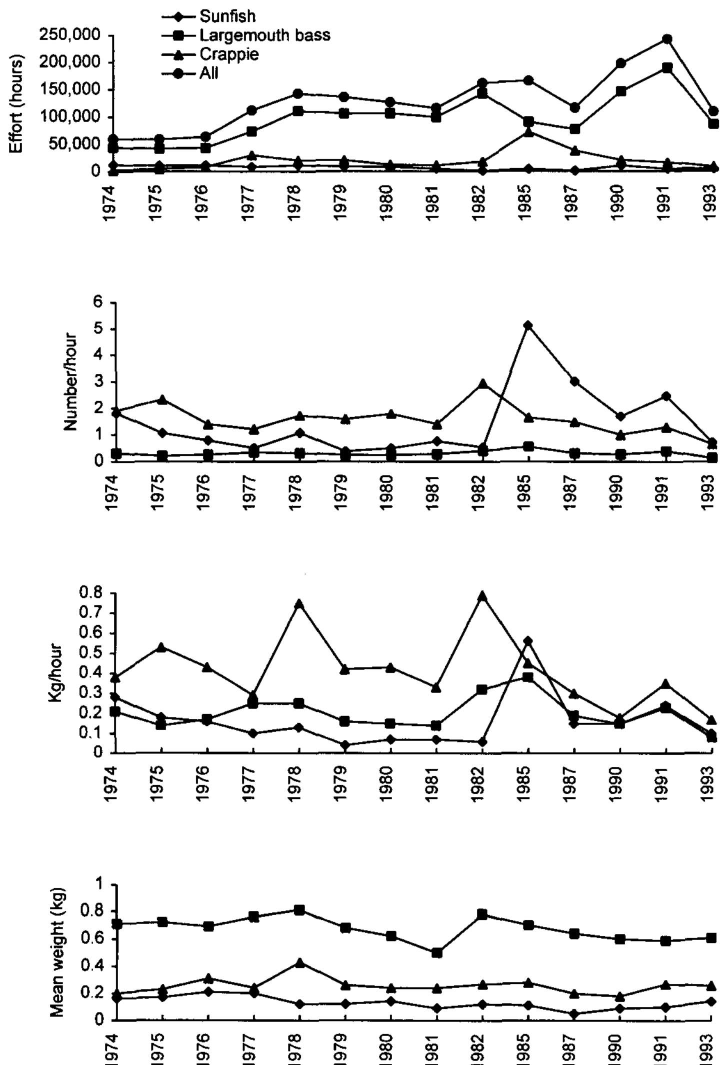

Figure 2. Effort, harvest rates, and mean weight of fish harvested by anglers fishing Keowee Reservoir, South Carolina. Sunfish = *Lepomis* spp., crappie = *Pomoxis* spp., and all = all species.

and angler harvest in Keowee Reservoir. The only major observable change that could be directly related to ONS's operation was increased effort and harvest of fish by anglers fishing Zone 2. The apparent attraction of fish to this small area of the reservoir and the associated increase in effort and harvest (primarily in winter) could result in the overharvest of fish in a low productivity system like Keowee Reservoir. Presently, this does not appear to have occurred. Fish popu-

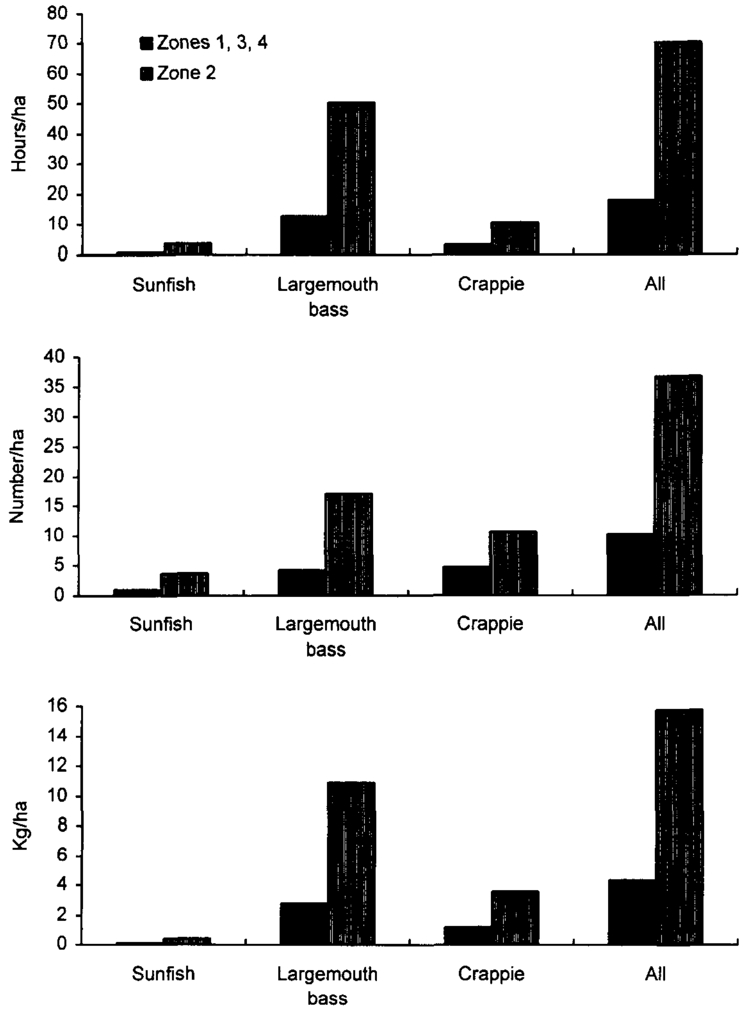

Figure 3. Effort (hours/ha) and harvest (*N*/ha and kg/ha) of fish by anglers fishing Keowee Reservoir, South Carolina. Sunfish = *Lepomis* spp., crappie = *Pomoxis* spp., and all = all species. See Figure 1 for locations of creel zones.

lations, fishing effort, and angler harvest will continue to be monitored in Keowee Reservoir with special emphasis given to that area around ONS. If effort and harvest by anglers fishing this zone increases significantly, a more restrictive harvest regulation may have to be implemented. This could be catch-and-release fishing in Zone 2 during winter or simply closing Zone 2 to fishing. The heated-water outfall areas of most cooling reservoirs have the potential to concentrate fish. These concentrations make fish more vulnerable to anglers and winter harvest here should be routinely monitored.

Table 2. Estimated effort (hours/ha) and harvest (*N*/ha and kg/ha) of fish by anglers fishing Keowee Reservoir, South Carolina, and other nearby Savannah River reservoirs.

			Sunfish[a]		Largemouth bass		Crappie[b]	
Reservoir	Year	Hr/ha	*N*/ha	Kg/ha	*N*/ha	Kg/ha	*N*/ha	Kg/ha
Keowee	1990	26.49	2.30	0.20	5.03	3.01	2.76	0.50
(present study)	1991	32.45	1.35	0.13	9.64	5.71	2.73	0.74
	1993	14.58	0.43	0.06	1.53	0.94	0.72	0.19
Jocassee	1990	22.10	1.39	0.21	1.37	1.00	0.27	0.06
(Barwick et al. 1994)	1991	19.52	1.74	0.19	1.22	1.15	0.19	0.03
	1992	29.16	1.63	0.17	1.20	1.43	0.30	0.08
	1993	27.04	1.99	0.18	1.59	1.77	0.30	0.07
Hartwell	1989	42.20	1.69	0.14	10.82	6.45	7.06	1.39
(Self 1991)	1990	25.78	1.35	0.13	4.27	3.12	3.37	0.88
Russell	1992	59.02	1.54	0.05	8.31	7.45	15.66	3.98
(Bales 1993, 1994)	1993	46.49	1.89	0.07	5.88	3.89	11.42	1.31
Thurmond	1992	55.76	2.93	0.23	7.40	5.89	8.18	2.25
(Bales 1993, 1994)	1993	49.98	3.68	0.49	6.44	4.00	5.95	1.40

[a]*Lepomis* spp. [b]*Pomoxis* spp.

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