Fish Distribution and Abundance Below a Southeastern Hydropower Dam

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Abstract: Releases of large volumes of water from low-level release ports during generation of peaking hydropower at Hartwell Dam, Georgia-South Carolina, resulted in large daily flow fluctuations and altered water quality in a section of the Savannah River. Flows ranged from a minimum of 3 m^3/sec during nongeneration to 665 m^3/sec during generation. Thermal stratification in Hartwell Reservoir generally resulted in low water temperatures ($\leq$20 C) throughout the 14-km study area and low dissolved oxygen concentrations ($<$3 mg/l) in the 2-km section of the river immediately below the dam. Distribution of fish species was similar at all sampling locations, but abundance generally increased downstream. Major factors affecting fish abundance below Hartwell Dam appeared to be recruitment of fish from the reservoir, a reduction in habitat diversity just below the dam, water temperatures suitable for sunfish spawning, and stocking of rainbow and brown trout (*Salmo gairdneri* and *S. trutta*).

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Construction and operation of large multipurpose reservoirs on many of the rivers in the United States have adversely affected native riverine fish populations. The most obvious and most often studied effects occur in the area inundated by the reservoir; however, increasing emphasis is being given to impacts on fish in the tailwater (the section of the river below the dam that is affected by reservoir releases).

Effects on the tailwater are most severe when water is released through discharge structures located near the bottom of reservoirs that thermally stratify in summer. Such releases in the southeastern United States generally

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result in a significant reduction in downstream warmwater fish populations (Pfitzer 1962, Brown et al. 1968, Edwards 1978, Gilbert and Reinert 1978). Hypolimnetic releases that lower tailwater temperatures may delay or inhibit spawning and thereby limit the reproduction of fish that enter the tailwater from the reservoir or downstream tributaries. Because recruitment is usually insufficient to maintain abundant warmwater fish populations, the tailwater may be managed as a put-and-take fishery for rainbow and brown trout (Axon 1974). In addition, low concentrations of dissolved oxygen (DO) and increased levels of iron, manganese, sulfides, and ammonia are sometimes present in discharges during late summer and fall (due to anoxic conditions in the reservoir's hypolimnion), and may further affect both warmwater and coldwater fish populations in downstream areas (Grizzle 1980, 1981).

Since the factors controlling distribution and abundance of tailwater fish populations are not well understood, the U.S. Army Corps of Engineers contracted with the National Reservoir Research Program, U.S. Fish and Wildlife Service, to initiate a comprehensive study of tailwater biota. Southeast Reservoir Investigations studied Hartwell Reservoir Tailwater—a peaking hydropower project with a put-and-take trout fishery. The objective of this paper is to describe the distribution and abundance of fish in the Hartwell Tailwater where extreme daily flow variations are experienced on weekdays. Funds were provided by the Environmental and Water Quality Operational Studies program sponsored by the Office, Chief of Engineers, under interagency agreement IAA WES79-04.

Methods

Completion of Hartwell Dam in 1961 by the U.S. Army Corps of Engineers created Hartwell Reservoir (22,640 ha) on the upper reaches of the Savannah River between Georgia and South Carolina. This impoundment is a warm monomictic reservoir with surface water temperatures ranging from about 7 C in winter to 30 C in summer. Thermal stratification usually begins in March and the thermocline is located at a depth of 10 to 20 m from June through September. Associated with the development of thermal stratification is a reduction in metalimnetic and hypolimnetic DO concentrations. The loss of DO continues throughout summer, concentrations generally being lowest in September or October.

The Hartwell Reservoir Tailwater consists of alternating pool and riffle habitat with extensive outcrops of bedrock. During nongeneration (flows of about 3–11 m^3/sec), the depth of natural pools in the tailwater rarely exceeds 5 m, and averages about 0.6 m. During power generation (264 megawatts), however, flows in the tailwater can increase to 665 m^3/sec and the average depth of the tailwater is increased by 2 m. Water used for the generation of electricity is released through powerhouse intake structures located at a center-line depth of 30 m when the reservoir is at full pool (201.2 m above mean sea level). Generation normally occurs on weekdays in the mornings and evenings during fall, winter, and spring and during the afternoon and evening during summer. Occasionally during periods of heavy rain in winter and spring, water may be released for 16 hours per day for flood control. Releases generally do not occur on weekends except as needed for flood control and to prevent summer tailwater temperatures from becoming too high for trout (>20 C).

Water quality in the Hartwell Tailwater is generally controlled by conditions in Hartwell Reservoir at the depth of the intakes. Minimum water temperatures of 7 C generally occur in February and increase through September or October when maximum temperatures on weekdays reach 20 C. During summer, however, temperatures near 25 C have been noted on Monday morning before normal weekday generation began, even though some weekend generation occurred. Concentrations of DO usually exceed 5 mg/l except in a short stretch just below the dam, where concentrations periodically drop as low as 2.2 mg/l in late summer or early fall. The usual ranges in concentrations (mg/l) of other chemicals follow: unfiltered iron, 0–1.213; manganese, 0.006–0.383; total sulfides, 0–1.56; and ammonia, 0–0.1.

Estimates of fish distribution and abundance in the Hartwell Tailwater were obtained by electrofishing and sampling with rotenone. Electrofishing samples were collected at 6-week intervals from April through October 1979 and quarterly (February, May, July, and October) in 1980 at 3 stations located 1.0 km (U.S. Highway 29), 4.0 km (S. C. Highway 181), and 12.1 km (S. C. Highway 184) downstream from Hartwell Dam. Electrofishing samples were also collected monthly from February through November 1980 in the stilling basin just below Hartwell Dam. A boat-mounted Smith-Root[1] Type VI-A electrofishing unit was used in conjunction with a 2-kilowatt generator. The unit was operated in a pulsed D.C. mode (120 pulses per second with a 4 millisecond pulse width) at a voltage sufficient to draw 1.5–2.0 amperes. Sampling was conducted at night during nongeneration periods and consisted of electrofishing the perimeter of each sampling pool (Table 1). All immobilized fish were collected and placed in a Styrofoam ice chest filled with water and equipped with a 12-volt agitator to maintain adequate DO concentrations. All fish collected were anesthetized with quinaldine, measured (total length in millimeters), weighed (nearest 1.0 g), and returned to the sampling pools.

[1] Reference to trade names does not imply government endorsement of commercial products.

Table 1. Description of the Fish Sampling Pools in the Hartwell Tailwater, Georgia-South Carolina

Collecting Method and Station	Distance Below Dam (km)	Surface Area (hectares)	Description
Electrofishing			
Stilling basin	Adjoining dam	6.1	Large pool excavated from bedrock. Shoreline composed of about 95% bedrock. Contained few backwater areas and little vegetation (mostly blue-green and filamentous algae). Sampling perimeter was 0.76 km.
Highway 29	1.0	2.4	Long, shallow pool with outcrops of bedrock. Shoreline composed mostly of bedrock (65%) or forested bank with a few fallen trees. Contained few backwater areas and little vegetation (mostly blue-green and filamentous algae). Sampling perimeter was 1.5 km.
Highway 181	4.0	2.6	Long, shallow pool with outcrops of bedrock. Shoreline composed mostly of bedrock (70%) or forested bank with a few fallen trees. Contained some backwater areas with sand and gravel bars. Vegetation sparse and composed mostly of blue-green or filamentous algae, but some aquatic macrophytes (*Fontinalis* sp.) present. Sampling perimeter was 1.4 km.
Highway 184	12.1	3.0	Long, shallow pool with outcrops of bedrock. Shoreline composed mostly of bedrock (55%) or forested bank with fallen trees. Contained numerous backwater areas with some sand and gravel bars. Vegetation sparse and composed mostly of blue-green algae, but some aquatic macrophytes (*Podostemum* sp.) present. Sampling perimeter was 1.8 km.
Rotenone			
Highway 29	0.7	0.6	Small, shallow pool with outcrops of bedrock. Shoreline almost entirely bedrock (95%). Vegetation similar to that in the electrofishing pool in this area.
Highway 181	5.0	0.4	Small, shallow pool with outcrops of bedrock. Shoreline almost entirely bedrock (95%). Vegetation sparse and composed mostly of blue-green and filamentous algae.
Highway 184	13.5	0.4	Small, shallow pool with outcrops of bedrock. Contained a small backwater area with some forested bank and a few fallen trees. Vegetation sparse and composed mostly of blue-green algae and *Podostemum* sp.

We collected samples with rotenone in September 1980 from 3 pools (Table 1), using a technique similar to that described by Holder (1975) and Johnson and Pasch (1975). Water temperatures during this sampling ranged from 17.0 to 18.1 C. With an afternoon-evening generation schedule in effect at the Hartwell Powerhouse during September, we had only part of 1 day to collect the rotenone samples. Therefore, after all dying fish were recovered from the surface of the pool and from the block net, scuba divers searched the bottom for any remaining fish. All fish collected were sorted by species, separated into 25-mm length groups, and counted and weighed in aggregate by length group.

Results and Discussion

Thirty-nine species of fish (representing 9 families) and several hybrids were collected (Tables 2 and 3) and 4 additional species (longnose gar, *Lepisosteus osseus*; yellow bullhead, *Ictalurus natalis*; white crappie, *Pomoxis annularis*; and sauger, *Stizostedion canadense*) were collected during incidental sampling. These 43 species of fish (representing 10 families) were generally distributed similarly at all stations. However, only 30 species of fish were reported in the stilling basin, as compared with 38 at Highway 29, 39 at Highway 181, and 37 at Highway 184.

The presence of 43 species of fish in the Hartwell Tailwater results in one of the most diverse tailwater fish faunas downstream from a hypolimnetic-release reservoir in the southeastern United States. Similar tailwaters in the Southeast rarely contain more than 25 species of fish (Pfitzer 1962, Brown et al. 1968, Edwards 1978, Gilbert and Reinert 1978). Although this tailwater differed from other tailwaters in supporting a diverse assemblage of fish, it was similar to others in having few *Notropis* species (Pfitzer 1962, Brown et al. 1968, Bacon et al. 1969, Gilbert and Reinert 1978). Only spottail shiners (*N. hudsonius*) and whitefin shiners (*N. niveus*) were found at all stations (Tables 2 and 3).

Although species distributions was similar at most stations, abundance differed, and samples collected by electrofishing and rotenone presented conflicting patterns. Electrofishing samples (omitting data collected from the stilling basin) indicated that catch rates (kg/km of shoreline) were low at Highway 29, then increased and were similar downstream at Highways 181 and 184 (Table 2). On the other hand, samples collected with rotenone indicated that biomass (kg/hectare) was similar at Highways 29 and 181 and increased considerably downstream at Highway 184 (Table 3). Both sampling methods indicated that 6 families—trout, minnows, suckers, catfishes, sunfishes, and perches—composed >94% of the biomass collected at all stations.

Table 2. Mean Abundance of Fish in 10 Electrofishing Samples Collected from the Hartwell Tailwater, 1979–1980, Expressed as Numbers of Fish or Weight (kg) of Fish Per Kilometer of Shoreline Sampled. The Stilling Basin Adjoins Hartwell Dam and Stations Near Highways 29, 181, and 184 were 1.0, 4.0, and 12.1 km, Respectively, Downstream from Hartwell Dam.

	Station							
	Stilling Basin		Hwy 29		Hwy 181		Hwy 184	
Species	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Gizzard shad *Dorosoma cepedianum*	1.29	0.38	0.13	0.04	2.79	0.76	1.44	0.39
Threadfin shad *D. petenense*			0.13	T[a]				
Rainbow trout *Salmo gairdneri*	14.57	1.87	13.13	1.71	5.57	0.77	0.55	0.14
Brown trout *S. trutta*	0.43	0.05	7.53	1.32	2.64	0.73	0.39	0.26
Chain pickerel *Esox niger*			0.33	0.12	0.07	0.01		
Common carp *Cyprinus carpio*	2.29	5.12	0.27	0.60	2.71	7.35	1.89	4.92
Bluehead chub *Nocomis leptocephalus*	0.14	T	0.27	0.02			0.28	0.01
Golden shiner *Notemigonus crysoleucas*	0.14	T			0.07	T		
Spottail shiner *Notropis hudsonius*	42.43	0.41	9.00	0.10	51.07	0.67	18.00	0.26
Whitefin shiner *N. niveus*	5.29	0.03	1.13	0.01	0.57	T	0.06	T
Quillback *Carpiodes cyprinus*	1.14	0.78			0.07	0.15	0.22	0.21
Creek chubsucker *Erimyzon oblongus*	0.14	0.02	0.60	0.05	0.43	0.03	0.11	T
Northern hog sucker *Hypentelium nigricans*	0.14	0.03	0.07	0.04	2.64	0.76	2.33	0.56
Spotted sucker *Minytrema melanops*	0.57	0.37	0.80	0.43	0.43	0.40	1.11	1.15
Silver redhorse *Moxostoma anisurum*			0.07	0.01	4.36	5.25	6.89	6.33
Smallfin redhorse *M. robustum*			0.07	0.02	0.93	0.65	3.50	1.88
Snail bullhead *Ictalurus brunneus*					0.79	0.05	0.17	0.01
White catfish *I. catus*	0.57	0.05	0.13	T	0.36	0.06	0.22	0.03
Brown bullhead *I. nebulosus*	1.57	0.14	0.33	0.04	3.00	0.34	0.78	0.12
Flat bullhead *I. platycephalus*					0.14	0.01	0.06	T
White bass *Morone chrysops*	0.43	0.15	0.07	0.01	0.43	0.10	0.06	0.02
Striped bass *M. saxatilis*							0.06	0.01

Table 2. Continued

Species	Station							
	Stilling Basin		Hwy 29		Hwy 181		Hwy 184	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
M. (hybrid)	0.29	0.11			0.14	0.04	0.11	0.07
Redbreast sunfish *Lepomis auritus*	2.29	0.13	9.67	0.57	12.57	0.73	7.83	0.70
Green sunfish *L. cyanellus*	4.43	0.13	3.13	0.14	5.79	0.09	4.44	0.15
Pumpkinseed *L. gibbosus*	0.29	0.01	0.07	T				
Warmouth *L. gulosus*	0.43	0.01	0.20	0.01	0.29	0.02	0.28	0.01
Bluegill *L. macrochirus*	33.29	3.39	4.33	0.26	1.79	0.12	5.44	0.37
Redear sunfish *L. microlophus*	0.29	0.03	0.07	0.02				
Spotted sunfish *L. punctatus*					0.21	T	0.11	T
L. (hybrid)	0.29	0.03	0.07	T			0.17	0.01
Redeye bass *Micropterus coosae*	0.43	0.13						
Largemouth bass *M. salmoides*	1.43	0.77	1.07	0.38	0.36	0.05	1.22	0.64
Black crappie *Pomoxis nigromaculatus*	0.71	0.07						
Yellow perch *Perca flavescens*	3.00	0.36	0.47	0.03	1.29	0.11	4.22	0.57
Blackbanded darter *Percina nigrofasciata*			0.07	T	0.43	T	0.61	T
Walleye *Stizostedion vitreum vitreum*	3.71	3.22	0.07	0.05	0.07	0.09		
Total	122.02	17.79	53.28	5.98	102.01	19.34	62.55	18.82

[a] T = trace (< 0.005 kg/km)

Inasmuch as electrofishing samples were generally collected on 10 occasions over a 2-year period (spatial and seasonal variations were consistent for all 10 periods) and it is more difficult to sample a given amount of similar habitat with rotenone than by electrofishing, data collected by electrofishing are probably sounder than rotenone data as a basis for between-station comparisons of fish abundance in Hartwell Tailwater. However, the rotenone collections are useful because they provide the most reliable estimates of fish biomass (kg/hectare) for pools in the tailwater study area. Also, several species were collected with rotenone that were not taken by electrofishing.

Our observations and those of Matter et al. (1983) indicate that scour forces are associated with the large volumes of water released from Hartwell Dam during generation and that these forces may affect fish abundance at

Table 3. Standing Crop Estimates of Fish in Samples Collected With Rotenone from the Hartwell Tailwater, September 1980. Stations Near Highways 29, 181, and 184 were 0.7, 5.0, and 13.5 km, Respectively, Downstream from the Hartwell Dam.

	Number/hectare			Kilograms/hectare		
Species	Hwy 29	Hwy 181	Hwy 184	Hwy 29	Hwy 181	Hwy 184
Blueback herring *Alosa aestivalis*		2			0.14	
Gizzard shad		5	8		1.11	1.49
Rainbow trout	27	208		1.81	13.83	
Brown trout	2			0.17		
Common carp	2			4.21		
Bluehead chub	63	5	2	0.84	T[a]	0.02
Unidentified shiner *Notropis* sp. (*chalybaeus?*)	22		2	T		T
Spottail shiner	1,490	2		13.60	0.03	
Whitefin shiner	15			0.11		
Northern hog sucker	13		10	2.04		2.29
Spotted sucker			12			5.57
Silver redhorse			108			69.90
Smallfin redhorse	2		35	0.20		6.87
Snail bullhead		48	22		1.82	1.21
White catfish	45	2		0.85	T	
Brown bullhead	2	8	2	0.30	0.73	0.22
Flat bullhead		12	15		0.46	0.99
Margined madtom *Noturus insignis*			5			0.09
Redbreast sunfish	17	2	250	0.90	0.25	12.08
Green sunfish	45	68	132	2.42	2.22	2.55
Pumpkinseed			2			0.26
Warmouth			12			0.32
Bluegill		2	240		0.05	13.73
Redear sunfish			2			0.10
Lepomis (hybrid)		2			0.04	
Largemouth bass			18			17.94
Black crappie			2			0.18
Swamp darter *Etheostoma fusiforme*			8			0.02
Yellow perch		15	20		2.41	3.36
Blackbanded darter	33	35	118	0.12	0.14	0.20
Grand Total	1,778	416	1,025	27.57	23.23	139.39

[a] T = trace (< 0.005 kg/hectare)

some stations. The scour action has resulted in extensive streambed armoring (a condition resulting from large releases of reservoir water having little or no sediment sluicing away fine particles from the river bed, leaving an armor-like layer of cobbles and rubble), sparse aquatic vegetation, and a reduction in the quantity of desirable fish habitat in the stilling basin and at Highway

29. These scour forces are apparently reduced at the downstream stations because there are more aquatic macrophytes, less armoring, and a greater quantity of desirable fish habitat. Low DO was not a problem at the 2 downstream stations. On the basis of physical characteristics of the stations, fish abundance would be expected to be low in the stilling basin and at Highway 29, and then increase downstream. However, this expectation did not hold.

Electrofishing at all 4 sampling stations indicated that catch rates (kg/km of shoreline) in the stilling basin were considerably higher than those 1 km downstream (Highway 29) and were similar to those 4 and 12 km (Highways 181 and 184) downstream (Table 2). Although similar estimates were noted in the stilling basin and at Highways 181 and 184, common carp (*Cyprinus carpio*), bluegills (*Lepomis macrochirus*), and walleyes (*Stizostedion vitreum vitreum*) dominated biomass estimates in the stilling basin, and common carp and several suckers—northern hog sucker (*Hypentelium nigricans*), spotted sucker (*Minytrema melanops*), silver redhorse (*Moxostoma anisurum*), and smallfin redhorse (*M. robustum*)—dominated the biomass estimates at Highways 181 and 184. Stocked trout dominated biomass estimates at Highway 29.

Since common carp, bluegills, and walleyes dominated the biomass estimates in the stilling basin and not at Highway 29, it seems reasonable that these fish may be entering the tailwater from Hartwell Reservoir. The loss of fish (juveniles and adults) from reservoirs during power generation is common (Pfitzer 1962, Walburg 1971, Groen and Schroeder 1978). It is also possible that some of these fish may migrate upstream (although our study did not indicate this) and concentrate below the dam, increasing their abundances in the stilling basin, or that some of these fish naturally prefer the habitat found in the stilling basin (a large deep pool) over that at Highway 29.

Disregarding common carp, bluegills, and walleyes in the stilling basin, rainbow and brown trout were the only major group of fish that were more abundant in the stilling basin and at Highway 29 than at the 2 remaining downstream stations (Table 2). Trout distribution in the tailwater is indicative of stocking and fishing pressure rather than of trout behavior. During spring and early summer, most trout are stocked near Highway 29. Stocking is curtailed as summer progresses and trout are stocked at Highway 181 to avoid the low DO concentrations at Highway 29 at this time.

For most other species, catch rates were generally lowest in the stilling basin and at Highway 29 and highest at either Highways 181 or 184. This abundance pattern at the 4 stations was probably related to the amount of suitable habitat and food available in the various areas. Farther downstream, the river widens and there are more backwaters that create numerous habitats suitable for resting, spawning, and feeding. Also, extensive outcrops of bedrock probably provide refuge for fish during power generation.

The importance of water temperatures on fish occurrence in the Hartwell Tailwater is unknown, because no preimpoundment data are available for comparison. Water temperatures in the tailwater reach 20 C on weekdays and are somewhat higher on weekends. According to Carlander (1977), these temperatures are sufficient for most sunfishes to spawn and may explain why they are the most diverse group of fish in Hartwell Tailwater, whereas they are normally absent or present in only small numbers in other southeastern tailwaters with low-level release ports. For example, Brown et al. (1968) found few sunfishes in 3 Arkansas tailwaters where water temperatures rarely exceeded 17 C.

Information on southeastern tailwater fish populations reported in the literature suggests that the number of species present and possibly fish production are regulated primarily by temperature. Maximum water temperatures below 17 C generally result in small numbers of species, whereas many species of fish are usually found in tailwaters with slightly higher temperatures. Therefore, it may be possible to increase temperatures and fish production in some tailwaters by using multiple inlet structures, as suggested by Hudson and Lorenzen (1981), or by constructing subimpoundments below dams. A subimpoundment with storage capacity would minimize the effect of the scour forces created during generation while increasing downstream water temperatures and possibly provide a minimum flow in the river below the subimpoundment. However, the use of subimpoundments to improve tailwater fisheries is probably restricted to dams with discharges $<300\ m^3/sec$. Otherwise, the subimpoundment is so large that construction is not economically feasible and most of the existing tailwater would be inundated.

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