Hydroacoustic Assessment of Fish in Strom Thurmond Lake[1]

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Abstract: Mobile hydroacoustic surveys of 11 stations in J. Strom Thurmond (JST) Lake from February 1986 to October 1988 provided data to aid in identifying critical areas, times, and water release regimes for fish relative to proposed pumpback of water from JST Lake to Richard B. Russell (RBR) Lake. Mean relative biomass ($\text{volts}^2/\text{m}^2$) usually was significantly higher in the tailrace (0–450 m below RBR Dam) than in the tailwater (1–7 km below RBR Dam), tributary, or lake areas in spring and summer; whereas in fall and winter, biomass was often lower than or did not differ from that in other areas. Highest numbers of fish occurred in the tailrace from May through September, probably because of blockage of upstream spawning migrations in spring and attraction to cold, oxygenated water released from RBR Dam in summer. Mean relative biomass in the tailwater 1–7 km below RBR Dam either was lower than that in warm-water tributaries and lake areas, or means did not differ significantly. Overall, mean relative biomass was significantly lower in the tailwater 1–3 km below RBR Dam than it was in the tailrace upstream or in the tailwater 4–7 km below RBR Dam. Mean densities in the tailrace during night nongeneration surveys usually were higher than those observed during either daytime surveys, under any operational regime, or during night postgeneration surveys. Fish densities in the tailrace generally were highest in areas over deep water within 50 m of RBR Dam. Predicted pumpback velocities and the relative biomass of fishes in the tailrace and tailwater suggest that the tailrace is the most critical area for entrainment of fish, and blueback herring and other clupeids are most likely to be adversely affected.

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Impounded in 1955 as Clarks Hill Lake, J. Strom Thurmond (JST) Lake is located on the Savannah River between Georgia and South Carolina just below

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Richard B. Russell (RBR) Lake (impounded 1983). Thurmond Lake has a surface area of 28,260 ha, a mean depth of 10.97 m, and a thriving warm-water fishery. From 1977 to 1987, annual fishing pressure averaged 26.9 hours/ha and was directed primarily at largemouth bass (*Micropterus salmoides,* 36.4% of effort); crappie (*Pomoxis* spp., 34.4%); and white bass × striped bass hybrids (*Morone spp.,* 16.1%). Average annual harvest was about 311,500 crappie, 124,100 largemouth bass, 84,000 sunfish (*Lepomis* spp.), 44,300 white bass × striped bass hybrids, 24,800 catfish (*Ictalurus* spp.), 16,700 white bass (*Morone chrysops*), 7,000 striped bass (*M. saxatilis*), and 7,000 "other" species (U.S. Army Corps of Engineers 1990). Commercial fishermen harvest large numbers of blueback herring (*Alosa aestivalis*) for bait in the tailrace and tailwater below RBR Dam.

As of 1989, the Savannah District, U.S. Army Corps of Engineers, began installing 4 75 megawatt reversible pump turbines to supplement 4 existing conventional turbines. Each pump turbine can be used as a conventional generator during times of peak power demand or as a pump during non-peak hours. The new turbines would increase the generating capacity of RBR Dam from 300 to 600 megawatts. It was believed the effects of pumpback (flows from 176 to 702 m^3/sec) and generation with more than 4 units (flows from 906 to 1,699 m^3/sec) might adversely impact the JST Lake fishery. Consequently, the Savannah District sponsored mobile hydroacoustic surveys of fish in JST Lake as part of the RBR Fish Entrainment Study. Mobile hydroacoustics have been used to aid in assessing possible impacts of pump-storage operations on fishes in Twin Lakes, Colorado (Thorne and Thomas 1981), Lake Mead, Nevada, (BioSonics 1987), and Lake Jocassee, South Carolina (Don Degan, pers. commun.). The objective of monitoring JST Lake was to document temporal and spatial distributions of fish before pumpback, thereby providing a basis for evaluating possible lake-wide effects after 1991. In this paper, we compared the relative biomass of fish among areas of the lake and seasons of the year, identified areas and fishes most likely to be adversely affected by pumpback (based upon fishery data and predicted pumpback velocities), and examined changes in the distribution of fish in RBR tailrace among seasons and operational regimes.

Methods

Equipment and Sampling

Hydroacoustic equipment included a BioSonics model 101 echo sounder; a 6 × 15 degree, dual beam, 420 KHz transducer; and a BioSonics model 171 tape-recorder interface. Echoes were monitored with an Hitachi oscilloscope, charted with an EPC model 1600 chart recorder, digitized with a Sony digitizer, and recorded with a Sony VCR. Video cassettes were processed by BioSonics, Inc., Seattle, Washington.

A BioSonics model 181 dual-beam processor was used to identify single fish echoes and to compute target strength, which is the decibel equivalent of the backscattering cross section of a fish (σbs in m^2/fish) and a measure of echo reflecting power toward a transducer. Target strengths have been correlated with fish lengths (e.g., Love 1977). A BioSonics model 121 echo integrator was used to accumulate echo intensities from fish and provided estimates of $volts^2$ per transect segment and 1-m depth interval. Echo integration data have been correlated with catch-per-unit-effort data (Thorne 1983). In processing, transects were divided into 10 segments of approximately equal length by sampling time.

A 0.6-m long fiberglass stabilizing fin housing a dual beam transducer was suspended just below the water's surface off the bow of an aluminum boat. The boat was driven slowly along each transect at a nearly constant speed (ca. 2.2 m/sec in tailrace surveys and 2.8 m/sec in other surveys), so that all segments within transects were sampled with approximately equal effort. Electronic equipment was powered with a portable gasoline generator.

Four or more transects were sampled at each of 11 stations in JST Lake from February 1986 through September 1988 (Fig. 1). Stations were categorized into 4 areas. The tailrace below RBR Dam (Station 1) had 12 transects parallel to and within 450 m of RBR Dam (1986–88) and 5–8 transects perpendicular to the dam and extending from the pump-turbine bays and the spillway to a buoy line 250 m downstream (1987–88). The tailwater 1–7 km below Russell Dam (Station 2) had 11 transects (13–23). Tributaries other than the Savannah River (stations 5, 6, and 11) each had 4 transects in 1986 and 11 in 1987–88. Lake stations (7–10) had 4 transects apiece.

Tailrace and tailwater areas were surveyed more frequently than tributary or lake areas because of emphasis on seasonal and operational effects. Tailrace transects were sampled once monthly under each of 4 operational regimes: 1) postgeneration surveys were done during the day or night immediately after generation-induced turbulence dissipated; 2) day nongeneration surveys were done at least 6 hours after generation ended; 3) night nongeneration surveys were done at least 1 hour after sunset on a generation moratorium weekend (6–24 hours after any generation); and 4) generation surveys were done monthly during power generation from July 1987 through September 1988, usually once at night and once during the day. Postgeneration and day and night nongeneration surveys sampled the 12 transects parallel to the face of RBR Dam. Generation surveys sampled the 5 to 8 transects perpendicular to the face of the dam because turbulence prevented sampling of parallel transects and the area below conventional turbines. The tailwater was sampled with the same frequency as the tailrace but only once monthly under prevailing operations during the day. It was surveyed once during the day and once at night in July, August, and September 1986 and in March, June, and August 1988. Tributary and main lake areas were surveyed once during the day in July, September, and December 1986, from March through July, September, and December 1987, and in March, June, and September 1988.

Sampling protocol also varied slightly among areas because of differences in the length and proximity of adjacent transects and the possibility of serial correlations in transect data. Tailrace and tailwater transects were shorter than transects in other

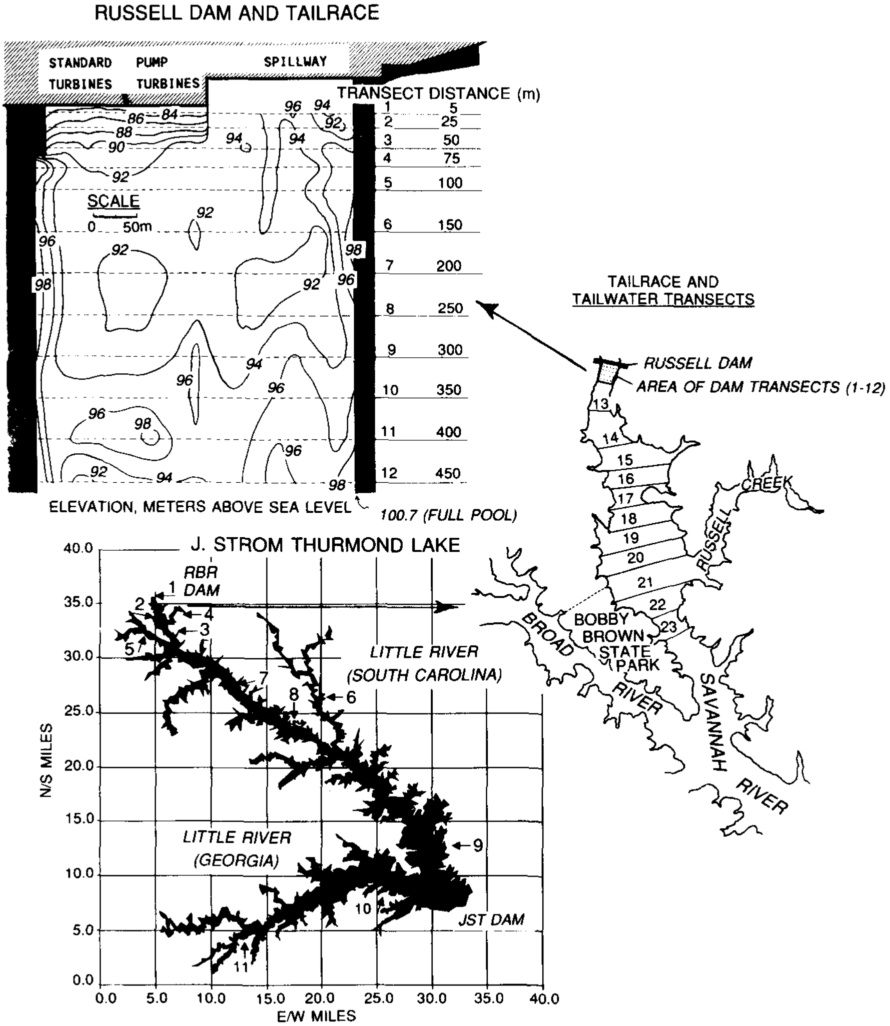

Figure 1. Beginning at the bottom and moving in a counter-clockwise direction, maps are: 1) J. Strom Thurmond Lake illustrating locations of 11 hydroacoustic survey stations, 2) Richard B. Russell tailrace and tailwater showing tailwater transects, and 3) Richard B. Russell tailrace showing transects and topographical characteristics.

areas and were relatively close together. They were always sampled from west to east, which made sampling of adjacent segments less continuous and facilitated comparisons of longitudinal and lateral distributions of fish. Sampling in the tailrace and tailwater usually began with the transects nearest RBR Dam and proceeded downstream. Transects 10–12 in the tailrace and 13–15 in the tailwater often could not be sampled during months of very low pool elevations in 1986 and 1988. Adjacent transects at tributary and lake stations were longer and further apart than tailrace or tailwater transects and therefore were sampled in alternate directions and not necessarily in the same direction every time.

The echo sounder and transducer were calibrated in January 1985, in July 1987, and April and September 1988 (Table 1), and field checks of calibrations were done in June 1985, June 1986, February, July, and October 1987, and in 7 of the 9 months surveyed in 1988. The echosounder, transducer, and cables were sent to BioSonics, Inc., where rigorous calibrations were done in a tank under controlled conditions. In field checks of calibrations, a standard target (ping-pong ball or steel sphere) was suspended in the dual acoustic beam, 9–10 m below the transducer, and voltage returns from hundreds or thousands of echoes were recorded. Average target strength and its variance were later calculated with field and calibration data as described by Traynor and Ehrenberg (1979) and compared to expected target strengths of similar standard targets. This information was used to track system performance and evaluate the applicability of tank calibration data.

The Georgia Cooperative Fishery Research Unit supplied supplemental fishery data by sampling fish with gill nets in JST Lake and with gill nets and a purse seine in RBR tailrace. Pelagic fishes are more effectively sampled than littoral fishes by these nets and acoustics. Four 76.2-m long, 2.4-m deep experimental gill nets with 6, 7.6-m panels of 25-, 38.1-, 50.8-, 63.5-, 76.2-, and 88.9-mm mesh were fished overnight at each of the 11 hydroacoustic stations. A 6.1 × 91.4 m long purse seine with 9.5-mm mesh was used to qualitatively sample pelagic fishes in RBR tailrace in 1988. The purse seine was used within 75 m of the dam during night generation moratoria, and species composition was

Table 1. Calibration statistics of hydroacoustic equipment and an estimate of a factor ($\mathrm{ACONST}_{(\sigma bs\,=\,1)}$) that when divided by the average back-scattering cross section of fish (σbs) and multiplied by relative biomass, yields an estimate of fish per m^2. Receiving sensitivity is referenced to 1 m. Decibels (dB) are referenced to 1 μPascal.

Year	Month	Pulse width (msec)	Source level at a −6 dB transmit setting (dB)	Narrow beam receiving sensitivity (dB)	Mean beam pattern factor $b^2(\theta)$	ACONST (σbs = 1)
1985	Jan	0.4	218.5	−148.04	0.000958	0.000198
1987	Jul	0.4	216.0	−152.80	0.001057	0.000956
1988	Apr	0.4	215.7	−151.84	0.000829	0.001046
1988	Sep	0.4	216.0	−152.50	0.000971	0.000971

estimated from subsamples of 300–400 fish from different parts of the net. Hydroacoustic surveys usually were conducted within 1 hour of purse seining, on the same night as nongeneration gill netting in the tailrace, and within 1 week of gill netting in other areas of JST Lake.

Data Handling and Statistics

We used relative biomass for all comparisons among areas and seasons and estimated fish density only for comparisons of fish distributions in RBR tailrace. The tailrace had the most reliable data on fish species composition and size distributions. We expressed relative biomass as volts^2/m^2 because it is more comparable over a wide range of water levels than the volumetric expression volts^2/m^3. We used relative biomass for most comparisons because it is less affected than density by electronic instability of equipment. Relative biomass depends only upon transmitted sound pressure level (sound 1 m from the transducer) and the through-system receiving sensitivity of the 6-degree transducer. By contrast, the factor used to expand relative biomass to density is made up of many elements, 4 of which are affected by the electronic stability of equipment: σbs = average backscattering cross section of a target (m^2 per fish); P_0 = transmitted sound pressure level 1 m from the transducer (μPascal); g_T = through-system receiving sensitivity of the transducer-sounder combination at 1 m (volts referenced to 1 μPascal); and $b^2(\theta)$ = mean squared beam-pattern weighting factor.

We compared mean relative biomass among 4 areas of JST Lake, among 3 sections of RBR tailwater, and among seasons within years for different areas or sections. Tailwater sections were 1–3 (transects 13–16), 3–5 (transects 17–20), and 5–7 km below RBR Dam transects (21–23; Fig. 1). Data from night nongeneration surveys of the tailrace were not included in this comparison because they were not comparable to data from day surveys of lake and tributary areas. Estimates of relative biomass were averaged to obtain 1 mean per transect and month from multiple estimates of tailrace transects (3 operational regimes) and replicate surveys of tailwater transects. Relative biomass data were not normally distributed and could not be made approximately normal by transformation, so we used analysis of variance on mean fractional ranks of relative biomass. This is equivalent to a Kruskal Wallis k-sample test or to Friedman's 2-way analysis in blocked designs (SAS Inst. Inc. 1985). Multiple F tests with α = 0.05 were used to determine which means differed significantly.

We expanded estimates of relative biomass in the tailrace to density by multiplying by a factor derived from the latest calibration (ACONST$_{\sigma bs = 1}$); Table 1) and then dividing this product by the average backscattering cross section of fish (σbs) from target strength data. This procedure is analogous to estimating fish density by dividing total fish standing crop by the average weight of fish, except that it includes many factors unique to fisheries acoustics.

We examined mean densities of fish in RBR tailrace in 3 ways. First, we compared mean densities of fish among the 4 operational regimes (postgeneration, day nongeneration, night nongeneration, and generation). Second, we divided night nongeneration transects into 5 groups and examined the longitudinal distribution of fish among groups of transects. Pooling transects made these data more amenable to analysis of variance by reducing the number of classes from 12 to 5. Third, we explored the lateral distribution of fish after pooling transect segments from west to east in 4 groups: 1) below conventional-turbine bays; 2) below pump-turbine bays; 3) below the west half of the spillway; and 4) below the east half of the spillway. We transformed densities (common log of fish/m^2 + 1), which made them nearly normal, and used analysis of variance in blocked and unblocked designs. Infrequently observed autocorrelations within transects or segments (<30 in 330 tests) were not considered sufficient to violate independence assumptions of tests. Multiple F tests were used to determine which means differed significantly ($\alpha = 0.05$).

Results and Discussion

Significant differences in January 1985 and July 1987 calibrations and results of field calibration tests made us suspect the accuracy of 4 months of data. Calibrations were relatively consistent from July 1987 through September 1988 (Table 1). Field calibration checks helped us identify when calibration changes probably occurred. In field tests of calibration, a standard on-axis target should have a target strength of about −42 decibels referenced to 1 μPascal (dB), but target strength may be 1–2 dB lower if many echoes are from a target that is off the main axis of the acoustic beam. The January 1985 calibration provided reasonable estimates of standard target strength in field calibration checks in June 1985 (−43.6 dB), June 1986 (−43.5 dB), and February 1987 (−43.9 dB), when <18% of measured echoes were from on-axis targets. However, the 1985 calibration provided an average target strength of −47.3 dB in a July 1987 calibration check in which 49% of echoes were from on-axis targets. When data from the July 1987 calibration were applied, average target strength for the same field test was more reasonable (−43.2 dB). Therefore, we concluded that the 1985 calibration probably was appropriate through February 1987 and that most changes in equipment sensitivity occurred during a 4-month period between March and June 1987.

We used the January 1985 calibration for data collected from February 1986 through June 1987, recognizing that we probably were underestimating relative biomass and density in some or possibly all months from March 1987 through June 1987. The ratio of the 1985 ACONST$_{(\sigma\text{bs} = 1)}$ to the July 1987 ACONST$_{(\sigma\text{bs} = 1)}$ (Table 1) suggested that relative biomass could be 63% low in some or all months from March through June 1987 if the July 1987 calibration were appropriate. Potential error in fish density calculated with the 1985 calibration was estimated by assuming that the average backscattering cross section (σbs) of fish decreased from 5.0×10^{-5} to 1.9×10^{-5} (as observed for standard targets in field calibration checks) and that ACONST$_{(\sigma\text{bs} = 1)}$ increased from 2.0×10^{-4} to 9.6×10^{-4}, as observed in rigorous calibrations (Table 1). The density expansion factor (ACONST = ACONST$_{(\sigma\text{bs} = 1)}$ /σbs could have been underestimated by a factor of 12.6, if we incorrectly applied the 1985 calibration, as follows: July 1987 ACONST = $9.6 \times 10^{-4}/1.9 \times 10^{-5}$ =

50.5; January 1985 ACONST = $2.0 \times 10^{-4}/5.0 \times 10^{-5} = 4.0$; and, 50.5/4.0 = 12.6.

Estimates of relative biomass or density are gross measures of the relative abundance of the entire fish community because fish species cannot be identified. From hydroacoustics data, we knew only that target-strength distributions varied more among seasons than among areas of JST Lake and that mean target strengths and fish lengths, calculated with Love's (1977) equation, did not differ significantly among areas (Schreiner 1990). Hydroacoustic methods require conventional fish sampling for species composition data.

The species composition of fish in the tailrace and tailwater was generally similar to that of other tributary stations within seasons (Van Den Avyle 1990*a*). In addition, the species composition of larval fishes and temporal trends in their abundance were similar among all parts of the reservoir in 1987 and 1988 (Van Den Avyle 1990*b*). Tailrace gill netting from 1986 to 1988 indicated that the composition of fish >200 mm (1,094 fish) was about 49% *Morone* spp. (35% white bass × striped bass hybrids, 8% striped bass, 5.5% white bass, and 1% white perch, *M. americana*), 25% suckers (Catostomidae), 17% clupeids (11% threadfin shad, *Dorosoma cepedianum;* 6% blueback herring); 3% sauger, *Stizostedion canadense;* 3% common carp, *Cyprinus carpio;* and 3% other fishes (e.g., black basses *Micropterus* spp.; gars *Lepisosteus* spp.; sunfishes; yellow perch, *Perca flavescens*). Purse-seine data from March through July 1988 indicated that 93%–100% of the small fish in open water near the dam were blueback herring. The purse seine, like gill nets, provided a biased picture of species composition, because it sampled only pelagic fishes of a select length range (ca. 110–190 mm). Two years of larval-fish sampling indicated that 82%–92% of the larval fish were clupeids (Van Den Avyle 1990*b*).

In comparisons among areas, mean relative biomass usually was significantly higher in RBR tailrace than in most other areas in spring and summer, whereas in fall and winter, it was often lower than or did not differ significantly from other means (Table 2). Differences probably were associated with blockage of upstream movements of fish by RBR Dam in spring and attraction of fish to releases of cold, oxygenated water from the dam in summer. Mean relative biomass in the tailwater 1–7 km below RBR Dam either was lower than that in warm-water tributaries (4 tests) and lake areas (3 tests) or the means did not differ significantly.

In comparisons among seasons (years blocked), mean fractional ranks of relative biomass usually were higher in summer than in other seasons and often were lowest in winter or spring. In the tailrace, seasons were ordered according to fractional ranks of relative biomass as follows: summer (0.67) > spring (0.50) ≈ fall (0.44) > winter (0.27). In the tailwater as a whole and sections 1–3 and 3–5 km below RBR Dam, ranks in summer (0.69–0.71) and fall (0.60–64) were significantly higher than mean ranks in winter (0.38–0.54) and spring (0.39–0.48). Seasonal ranks for the tailwater section 5–7 km below RBR Dam and lake area were similar: summer (0.63–0.68), fall (0.52–0.60), and winter (0.53–0.54)), but these ranks were higher than ranks in spring (0.35–0.38). The rank of tributary biomass in winter (0.63) did not differ significantly from that in fall (0.59) or summer (0.55),

Table 2. Effects of location in J. Strom Thurmond Lake on the mean relative biomass of fish. Mean fractional ranks of relative fish biomass are presented in tests by year and season, and those prefaced by the same letter did not differ significantly. Abbreviations are as follows: P = significance level; N = number of transects sampled; TAILR = tailrace, excluding generation moratorium surveys; TAILW = tailwater; TRIB = tributaries other than the Savannah River; and LAKE = lake areas.

Season	1986			1987			1988		
	$P = 0.0001$	Mean	N	$P = 0.0001$	Mean	N	$P = 0.0001$	Mean	N
Spring	TAILR A	0.65	36	TAILR A	0.44	36	TAILR A	0.68	33
	TAILW B	0.37	53	LAKE AB	0.38	36	LAKE B	0.53	12
				TRIB BC	0.31	99	TRIB BC	0.43	44
				TAILW C	0.23	55	TAILW C	0.36	27
	$P = 0.0001$	Mean	N	$P = 0.0001$	Mean	n	$P = 0.0013$	Mean	N
Summer	TAILR A	0.79	34	TAILR A	0.93	36	TAILR A	0.71	33
	TRIB A	0.79	12	LAKE B	0.64	24	TAILW AB	0.59	25
	TAILW B	0.50	31	TAILW B	0.61	33	LAKE B	0.52	12
	LAKE B	0.50	12	TRIB B	0.57	66	TRIB B	0.50	55
	$P = 0.0026$	Mean	N	$P = 0.9800$	Mean	N	$P = 0.0004$	Mean	N
Autumn	TRIB A	0.65	12	TAILR A	0.52	35	TAILR A	0.91	11
	TAILW B	0.47	25	TRIB A	0.50	33	TRIB B	0.67	33
	LAKE B	0.46	12	LAKE A	0.50	12	TAILW B	0.64	8
	TAILR B	0.34	28	TAILW A	0.49	30	LAKE B	0.54	12
	$P = 0.0010$	Mean	N	$P = 0.0001$	Mean	N			
Winter	TRIB A	0.55	33	TRIB A	0.76	33			
	LAKE B	0.36	12	LAKE A	0.68	8			
	TAILW BC	0.28	21	TAILR B	0.45	34			
	TAILR C	0.13	21	TAILW B	0.33	50			

but all ranks were significantly higher than the rank in spring (0.35). Relative biomass may be underestimated by transect sampling in spring because many fishes are in or near shallow water for spawning.

The shallow tailwater section 1–3 km below RBR Dam apparently does not provide as desirable habitat for fish as the tailrace or the last 3–7 km of tailwater, which are relatively deep and stratify thermally. The tailwater 1–3 km below RBR Dam had a significantly lower mean fractional rank of relative biomass (0.36) than the tailrace upstream (0.60) or the 2 tailwater sections downstream (0.44–0.47) in a test blocking years and seasons ($N = 694$). Means differed significantly among tailwater sections 3 times (summer 1986 and winter 1986 and 1987), each when biomass in the lowest section was significantly higher than that in the upper third of the tailwater. Mean fractional ranks were significantly lower for the tailwater 1–3 km below RBR Dam than they were for the tailrace in spring 1986–1988 (0.23–0.36 vs. 0.46–0.68), summer 1986–1987 (0.37–0.65 vs. 0.77–0.91), fall 1988 (0.44 vs. 0.88), and winter 1987 (0.23 vs. 0.46).

Morphometric and hydrologic conditions apparently made the first 1–3 km of the tailwater less desirable for fish than conditions in the tailrace or the lower 3–7 km of tailwater. The tailrace is deepest near RBR Dam, and bottom elevations increase from the base of the dam to about 1 km below it (Fig. 1). The first 1–3 km of tailwater is shallow, but depths increase in downstream sections 3–7 km below RBR Dam and include the hypolimnion of JST Lake. During summer generation, cold-water releases enter the tailrace, are forced over higher bottom elevations within about 1 km of RBR Dam, and then flush the uppermost tailwater section. Cold releases then pass through the middle section of tailwater as cold oxygenated underflows at normal pool elevations or as surface to bottom flows at low pool elevations. When summer releases are stopped for 6–18 hours, as in generation moratoria, water quality models 'T. Cole, USAE Waterways Exp. Sta. pers. commun.' and diel temperature profiles show that overflows of relatively warm surface water return to the tailrace, replacing cold water released previously. Flows of cold water during power generation and returning flows of relatively warm water move through the shallow upper third of the tailwater and subject it to rapid changes in water temperature. Deep tailrace areas within 50 m of RBR Dam and the last tailwater section (5–7 km below the dam) were less affected by these flows than the shallow section of tailwater 0.1–3 km below RBR Dam.

Night nongeneration periods appear to provide unique conditions that attract very high densities of fish to RBR tailrace. Mean densities during night nongeneration surveys usually were higher than those observed under other operational regimes, which most often were surveyed during the day (Table 3). However, differences were not limited to day versus night because night nongeneration densities also were significantly higher than densities in night postgeneration surveys in fall 1986 (5,189 vs. 456/ha), spring 1987 (17,023 vs. 5,605/ha), winter 1986 (1,252 vs. 68/ha), and summer 1988 (73,345 vs. 4,532/ha). The only difference between these 2 night surveys was time since generation (15 minutes vs. 6–24 hours). Returning surface flows of relatively warm water (22–28 C) after 6–18 hours of nongeneration could be important in attracting very high densities of fish during night generation moratoria. These flows may transport zooplankters to the tailrace and place them over and within 2–4 m of water with temperatures preferred by blueback herring (18–24 C at depths of 4 m). Generation may displace fish downstream or may cause them to seek eddies or submerged structure where they are less susceptible to entrainment and to detection by hydroacoustics. A variety of factors could account for observed day-night differences. Diel changes in fish distributions could make fish most detectable at night, when they are more randomly distributed and pelagic (Netsch 1971) and less apt to avoid a boat. Phantom midges (*Chaoborus* sp.) could cause significant overestimates of fish density in night surveys, but they were rare in the tailrace.

We observed significant differences in the longitudinal distribution of fish in RBR tailrace, but found no significant differences in lateral distributions in any year or season. Fish in the tailrace during night nongeneration surveys apparently preferred areas over deep water (>10 m deep at full pool elevations) within 50 m of the dam (Fig. 1). Mean densities were significantly higher within 50 m of RBR Dam (45,190/ha) than they were in tailrace areas 75–450 m downstream from the dam (8,864–23,522/ha) in a test with years and seasons blocked. Within years and seasons, differences were significant in spring 1986, summer 1986, and winter 1987.

Table 3. Effects of operational regimes on mean fish per m^2 in Richard B. Russell tailrace. Means prefaced by the same letter did not differ significantly ($\alpha = 0.05$). Abbreviations are as follows: P = significance level; N = number of transects sampled; PG = postgeneration; DNG = day nongeneration; NNG = night nongeneration (moratoria); GEN = generation.

Season	1986				1987				1988			
	$P = 0.0001$		Mean	*N*	$P = 0.573$		Mean	*N*	$P = 0.0010$		Mean	*N*
Spring	NNG	A	0.770	48	NNG	A	0.790	60	NNG	A	1.908	27
	PG	A	0.753	96	PG	A	0.749	96	PG	AB	0.780	27
	DNG	B	0.196	108	DNG	A	0.338	65	DNG	B	0.453	27
									GEN	B	0.150	24
	$P = 0.0001$		Mean	*N*	$P = 0.0720$		Mean	*N*	$P = 0.0001$		Mean	*N*
Summer	NNG	A	1.702	34	NNG	A	7.356	36	NNG	A	7.335	27
	PG	B	0.561	68	GEN	AB	5.730	31	DNG	B	1.393	25
	DNG	B	0.409	46	PG	AB	4.932	60	GEN	B	0.849	19
					DNG	B	1.125	36	PG	B	0.472	27
	$P = 0.0001$		Mean	*N*	$P = 0.0001$		Mean	*N*	$P = 0.0123$		Mean	*N*
Autumn	NNG	A	0.391	27	NNG	A	4.182	21	NNG	A	4.789	9
	PG	B	0.023	55	PG	B	1.213	30	PG	B	2.030	9
	DNG	B	0.010	25	DNG	B	0.395	30	DNG	B	1.759	9
					GEN	B	0.340	23	GEN	B	1.299	6
	$P = 0.0001$		Mean	*N*	$P = 0.0001$		Mean	*N*				
Winter	NNG	A	0.429	12	NNG	A	0.236	30				
	PG	B	0.009	30	PG	B	0.059	75				
	DNG	B	0.003	21	GEN	B	0.040	33				
					DNG	B	0.010	62				

Higher densities associated with areas over deep water were not an artifact of increased sample volume in deep areas because most fish within 50 m of the dam were within 5 m of the surface, although deep water (8–16 m) was available in front of the draft tube openings. Fish biomass located along transects ≥75 m from the dam was more uniformly distributed vertically in the 4–6 m of water column available. The sum of average fish biomass by year, season, and 1-m depth stratum at transects 1 and 2 during night nongeneration surveys indicated that 90.0 ± 11.2% SD of fish biomass was in the top third of the water column, and 99.5 ± 1.1% SD was above the top of the draft tube openings.

Seasonally, total numbers of fish estimated in night nongeneration surveys of RBR tailrace were significantly higher from May through September than they were from October through April every year (Fig. 2). We believe that about 90% of these fish were clupeids and that most were blueback herring, based upon purse-seine data and distributions of fish in the water. Also, the 90th percentile length of targets, calculated from all years of target strength data with Love's (1977) equation, was 259 mm in fall ($N = 5{,}399$), 242 mm in spring ($N = 10{,}739$), 224 mm in summer ($N = 16{,}814$), and 138 mm in winter ($N = 1{,}642$).

Hydroacoustics, hydraulic modeling, and supplemental netting of the fish community of JST Lake provided data helpful in assessing potential problems associated

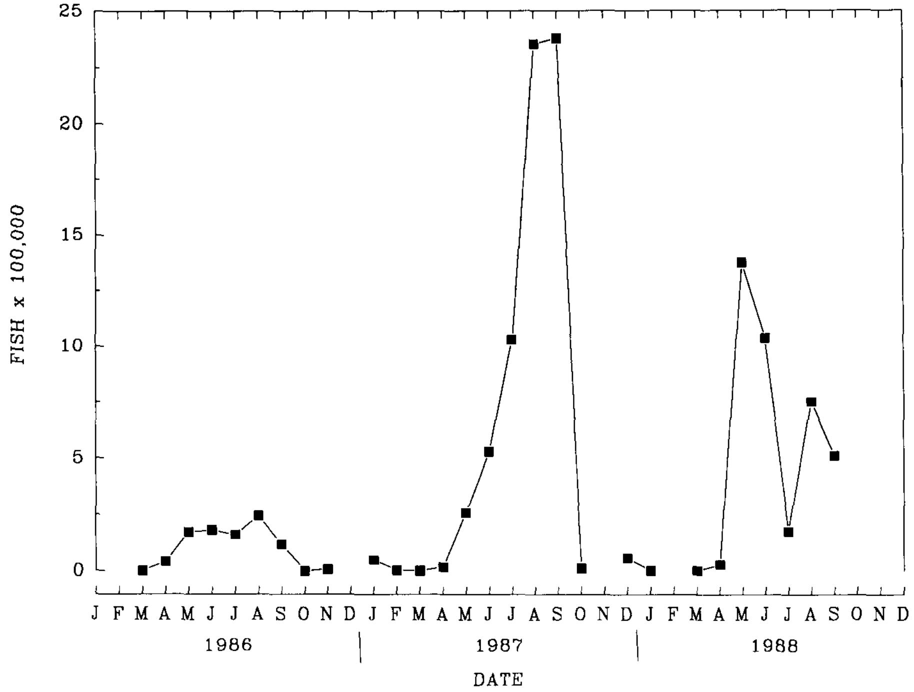

Figure 2. Seasonal variation in the total number of fish within 300 m of Richard B. Russell Dam during night nongeneration periods (1986–1988).

with future pumpback operations. During the growing season, the 11.2-ha tailrace immediately below RBR Dam usually supported more fish biomass than any other area of JST Lake, whereas biomass in the tailwater (especially the first 1–3 km below RBR Dam) was lower than or comparable to that in other areas of the lake. The tailrace deserves careful consideration relative to proposed pumpback operations because high fish densities are made up primarily of small pelagic clupeids that are highly vulnerable to entrainment. Other pelagic fishes such as adult striped bass and striped bass × white bass hybrids occur in the tailrace but are not expected to be entrained because they are strong swimmers (Bell 1986). Predicted approach velocities 15 m in front of pump-turbine bays and 0.3 m above the bottom ranged from 0.43 to 0.61 m/sec at normal pool elevations (Hite 1990). Water moving at these velocities undoubtedly would entrain small fish. However, the width of pump turbines bays is only 27% of the 366-m-wide tailrace, and substantial areas with lower velocities ($<$ 0.31 m/sec) should be available to provide refuge, particularly for species that prefer benthic or near-shore areas (e.g., largemouth bass, sauger, and lepomid sunfishes).

We believe lake-wide impacts are unlikely. The tailrace and 7-km long tailwater make up about 3% (800 ha) of the surface area of JST Lake, and velocities of $\leq$0.15

m/sec, predicted for the lower half of the tailwater 3.5–7 km below RBR Dam (Schneider 1990), should not entrain fish. Although the tailrace fishery is valuable, the species composition of fish in JST Lake is generally similar among areas within seasons, and the tailrace-tailwater species assemblage was not unique (Van Den Avyle 1990 *a, b*). Nevertheless, sizable data bases have and are being developed to help assess lake-wide impacts if they should occur.

Fish species composition and the 3-dimensional distribution of fish in the tailrace are important to the development of fish protection measures at RBR Dam. Blueback herring and threadfin shad numerically dominate the species composition of the tailrace and because of their small size (50–200 mm) and pelagic nature are most vulnerable to entrainment. The concentration of fish in the upper third of the water column and relatively uniform lateral distribution are viewed as positive characteristics because relatively low velocities are expected in the upper third of the water column near the face of the dam (Hite 1990) or in areas on either side of the pump turbines (Schneider 1990). However, high densities of clupeids in front of pump turbines in summer are a serious concern, and the Waterways Experiment Station has been experimenting with a prototype high-frequency sound system for keeping them from this area before and during pumpback.

Two valuable lessons for conducting mobile-hydroacoustic surveys are apparent from results of this preliminary study. First, rigorous calibration of equipment must be conducted annually, and field checks of calibration should be done at least once during monthly surveys. This protocol was adopted for all surveys of JST Lake in October 1988. Fortunately, undetected calibration changes in this study were limited to a 4-month period in 1987, and comparisons among lake areas or operational regimes would not be affected by temporal changes in equipment sensitivity because all areas and regimes were sampled monthly in 1 week each month. Although seasonal comparisons in 1987 may have been biased by underestimates of relative biomass from March through June, seasonal trends were similar to those observed in 1986 and 1988. Second, gill-net sampling should be designed or amended (if apriori information was not available), so that estimates of species composition are not overly biased by size selectivity. In this study, we avoided estimating densities of individual species, except in RBR tailrace, because gill nets with the smallest mesh (25.4 mm) did not sample fish <200 mm in proportion to their abundance in JST Lake. After October 1988, 12.7- and 19.1-mm mesh gill nets were added to gill-net complements.

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