Influence of River Discharge on Blueback Herring Abundance[1]

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Abstract: Adult and larval blueback herring (*Alosa aestivalis*) were sampled in the Santee River, South Carolina, during 1983 and 1984 under different discharge regimes. Discharge and water temperature were less variable in 1984, when at least 2 distinct peaks in abundance of adult herring were observed compared to 1 major peak in 1983. Adult and larval herring were more abundant in 1984 than 1983. The major contributor to larval abundance in 1984 appeared to be the later-occurring peak in adult herring abundance. Abrupt changes in discharge and water temperature in 1983 appeared to adversely impact spawning adults resulting in reduced numbers of herring larvae.

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The operation of dams and peaking hydroelectric facilities can result in rapid changes in discharge and such fluctuations can adversely impact downstream habitat and fish fauna (Petts 1984, Cushman 1985). Impacts associated with rapid fluctuating discharges include reductions in fish species diversity, abundance, standing crop biomass, fish condition, spawning success, egg and larval survival, success of migration, and fishery harvests (Fraser 1972, Holden 1979, Petts 1984, Cushman 1985). Most of the research on the effects of fluctuations in discharge on migratory fish involves salmon and trout, and very little has been done on other anadromous fishes, especially the alosids.

Blueback herring (*Alosa aestivalis*) is an important alosid species in South Carolina, serving as a key forage species for striped bass (Stevens 1961) and providing

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cut and live bait for commercial and sport fishermen (Curtis and Christie 1982). In this study, we examined adult and larval blueback herring abundance during 2 years of varying discharge and suggest possible explanations for observed differences in spawning success.

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Materials and Methods

Abundance of larval fish was determined at 5 sites in the Santee River system below Wilson Dam (Fig. 1). River sites were located at: 1) U.S. Highways 52 (US) landing (120 river km from the mouth); 2) 2 km below entrance of the rediversion canal at Laurel Hill (LH) landing (80 km); 3) at Jamestown (JT) landing (62 km); and 4) at Phoenix-McConnell (PM) landing (45 km). At these sites, the Santee River is broad (50–91 m) and shallow (1–7 m), and the bottom substrate particles are mainly sand and silt with bedrock outcrops and submerged stumps. A fifth site was located at Wee Tee Lake (WT), a small tributary which empties into the Santee River directly upstream from Jamestown sampling site (Fig. 1). Wee Tee Lake is a narrow (10–25 m) and shallow (1–10 m) backwater lake with bottom substrate rich in decomposing organic matter.

Sampling of larval herring was conducted every 2 days from 25 February to 30 May 1983 and from 20 February to 4 May 1984. Samples were taken from 0700 to

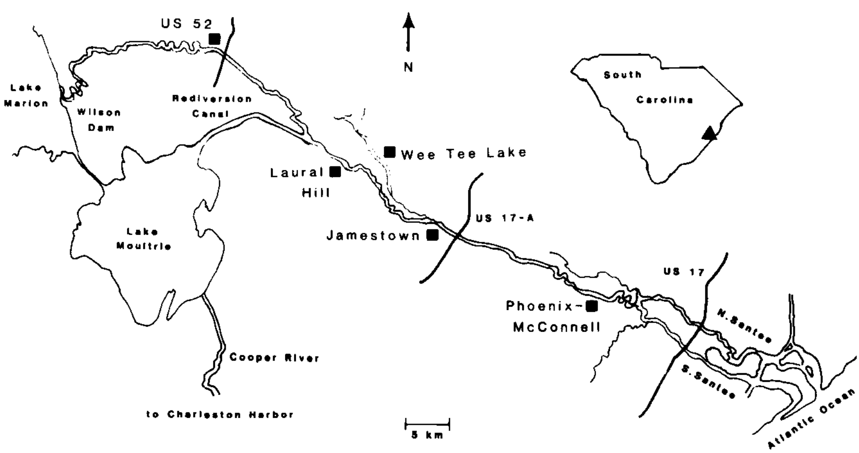

Figure 1. Sampling sites in the Santee River system. Sites are designated by closed boxes. Insert shows location of Santee River system within South Carolina.

1600 hours which enabled comparisons with data from previous studies of the Santee River (e.g., Meador et al. 1984). Order of sampling sites was randomly selected to minimize differences in larval catch due to varying light intensities with time of day (Loesch et al. 1982, Meador et al. 1984). Larval fish were sampled near the surface (< 0.5 m depth) by pushing a 2-m plankton net (0.5-m diam.; 0.526-mm mesh) in a bow-mounted frame on a 4.3-m boat (Meador and Bulak 1987). An estimate of water volume sampled was determined with a digital flow meter (Oceanics, Model 2030) mounted in the center of the mouth of the net (Marcy and Dahlberg 1980). Two tows were conducted in Wee Tee Lake and 6 tows at each river site. Tows were conducted while moving downstream for 5 minutes at a constant speed of 1 m/second. Speed was maintained with the aid of a resonating reed tachometer which permitted the conversion of boat vibrations to speed (Meador and Bulak 1987). Approximately 60 m^3 of water were filtered in each sample (West 1984).

Samples were fixed in the field with 5% buffered formalin. Later, blueback herring and other larval fish were sorted from the samples using a dissecting microscope (10x). Larval blueback herring included fish with a visible yolk sac or fish whose yolk had been absorbed but without a full complement of fin rays (Hubbs 1943). Blueback herring larvae were measured for total length (TL) to the nearest mm and then classified as "recently hatched" larvae (< 6.0 mm TL) or "older" larvae ($\geq$ 6.0 mm TL). Recently hatched larvae were assumed to have hatched 2–6 days prior to collection (Cianci 1969) and spawned near the sampling sites (Meador et al. 1984). Statistical analyses were restricted to recently hatched blueback herring.

Abundance was determined by computing the number of larval blueback herring caught per 100 m^3 of water sampled. Mean daily abundance was calculated for each collection day from the date of first occurrence to the last day larval herring were collected. Unequal variances (F ratio) in larval abundances among dates required log transformation. There were no significant differences ($P > 0.05$) in larval herring abundances among tows (by combining sites). Consequently, the larval catches from the tows were combined to calculate a daily value for each site. Abundances of recently hatched herring larvae were tested for significant differences among sites. The abundance of recently hatched larval herring at each site was also tested for correlations with average daily discharge, water temperature, and catch of adult herring. Correlations, F ratios, and Student's *t*-tests were calculated using the Statistical Analysis System developed by Barr et al. (1979). Significance level was set at $P \leq 0.05$.

Discharge statistics (m^3/second) were obtained from the Santee-Cooper Public Service Authority (B. Inabinette, pers. commun.). Under normal discharge conditions 15 m^3/second are released from Wilson Dam. Changes in daily discharge were calculated for both spawning seasons. Water temperature near the surface was measured at each site each sampling day and since these temperatures varied little ($\pm$ 1°C) among river sites, values were combined to obtain a daily mean water temperature. Water velocity was measured at mid-water depth at each site once a week. Comparisons of variance (F ratio) and means (*t*-test) were conducted on water temperature, log transformed values for average discharge, and log transformed values for daily changes in discharge to test for significant difference ($P \leq 0.05$) in these physical parameters between sample years.

Gillnetting for adult herring was conducted from 3 March to 13 April 1983 and from 1 March to 24 April 1984. Gillnets (61 × 1.83 m; 3.18-cm stretch mesh) were drifted from 1400 to 2000 hours 6 days a week. The gillnet site was at JT in 1983 until 23 March when high water inundated the boat ramp and forced sampling to be conducted at PM for the duration of 1983 season. PM was the only site sampled in 1984. Catch per unit effort was calculated as catch per minute (CPM) to give an index of the herring run. Correlation coefficients were computed between CPM and water temperature and discharge. Comparisons of means by *t*-test were conducted to test for significant differences between years in log transformed CPM values.

Results

1983 Spawning Season

Mean daily discharge from Wilson Dam from 20 February to 1 May was 386 m^3/second (± 326.5, SD) and the mean change in daily discharge was 84 m^3/second (± 120.4). Changes in daily discharge occurred on all but 7 days of the spring sampling season (Fig. 2). Water velocity during the sampling season averaged 0.8

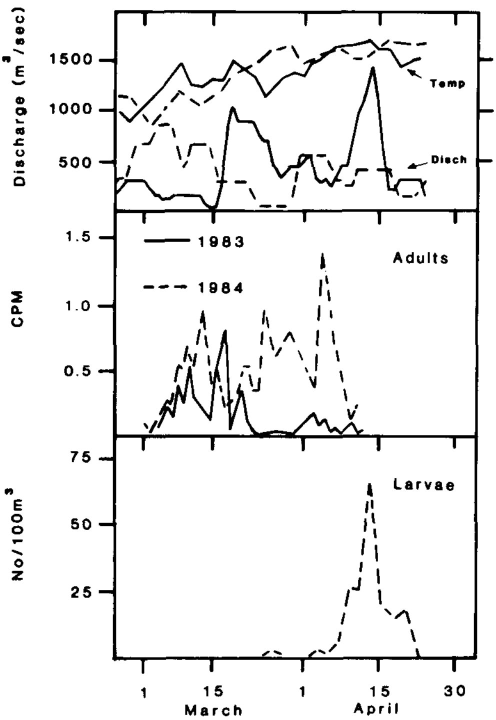

Figure 2. Abundance of recently hatched larval blueback herring (*N*/100 m^3), catch per minute (CPM) of adult herring, water temperature, and discharge from Wilson Dam in the Santee River system for the 1983 (solid line) and 1984 (broken line) sampling seasons.

m/second in Santee River and 0.2 m/second in Wee Tee Lake. Decreases in water temperature frequently followed increased discharges (Fig. 2). Mean water temperature fluctuated between 11°C and 15°C between 3 March and 6 April. Water temperature in the river reached 13°C, lowest recorded spawning temperature for blueback herring (Hawkins 1979), first on 8 March and remained above this temperature after 28 March (Fig. 2).

In 43 sampling days, 74 tows were conducted at WT and 1,043 at the Santee River sites. Larval fish (N = 381) from 15 taxa were collected from 6 April to 30 May 1983. The most numerous species was American shad (*Alosa sapidissima*); it comprised 61% of the total larval catch and had mean daily abundance of 0.70 larvae/100 m^3. Blueback herring had an abundance < 0.01 larvae per 100 m^3 water sampled. Only 5 larval blueback herring were caught and 4 were older larvae. Herring larvae were caught at water temperatures between 17°–20°C.

Adult herring were present in Santee River on 3 March, the first day gillnets were set. Average CPM for the season (3 Mar–13 Apr) was 0.16 adult herring. Adult herring CPM peaked at approximately 1 fish per minute 16–18 March but only few adult herring were caught after 18 March (Fig. 2). An increase in discharge of 1,000 m^3/second occurred from 16 to 19 March (Fig. 2). No statistically significant correlations were found, however, between daily discharge, change in daily discharge or water temperature and CPM.

1984 Spawning Season

Mean daily discharge of water from 20 February to 1 May was 391 m^3/second (± 240.9) with a mean change in daily discharge of 62 m^3/second (± 85.6). Greatest change in 1984 occurred when discharge increased from 15 m^3/second to 547 m^3/second from 28 to 31 March. There were 16 days during the sampling season with no reported change in discharge (Fig. 2). Mean water velocity during the sampling season was 0.9 m/second in Santee River and 0.3 in Wee Tee Lake. Mean water temperatures in Santee River reached 13°C on 16 March and 15°C on 23 March, and water temperatures were not observed below 15°C for the remainder of the season (Fig. 2).

During 36 sampling days 33 tows were made in WT and 903 at the river sites. Larval fish (N = 3,907) from 11 taxa were collected from 15 March to 4 May. Larval blueback herring constituted 80% of total larval catch, and 81% of these were recently hatched herring. Herring larvae were first collected at JT on 23 March and at all sites 4 days later. Water temperature was 15.5°C in Santee River and 17.0°C in Wee Tee Lake when herring larvae were first collected.

Larvae peaked on 14 April (Fig. 2) and this peak comprised 36% of the larvae collected in 1984. No statistically significant differences were detected in mean daily abundances of larvae among sites; however, 3 times more larvae were collected at the US site than any other site. The last larval herring were caught on 24 April, 10 days after peak catches of recently hatched larvae in Santee River (Fig. 2). Herring larvae were not collected on the next 4 sampling days and sampling was terminated.

Adult herring were present in the river on the first day of sampling (1 Mar 84). Peaks in daily herring CPM occurred from 8 to 15 March, and from 19 March to 6 April (Fig. 2). Average CPM for the season (1 Mar-24 Apr) was 0.50 herring. There were no significant correlations between daily discharge, change in daily discharge or water temperature and CPM.

1983 vs. 1984 Seasons

Mean discharge in 1983 (386 m^3/second) was similar to 1984 (391 m^3/second), but mean change in daily discharge was higher in 1983. Comparison of variance (F ratio) indicated that daily discharge varied significantly more in 1983 than in 1984. Coefficient of variation of mean daily discharge was 84.6% in 1983 and 61.6% in 1984. As expected, discharge was constant fewer days in 1983 than 1984. No significant differences were detected by *t*-test or F ratio between years in mean water temperature or the variance of water temperature, respectively.

Adult herring CPM was significantly greater in 1984 than in 1983. Correspondingly, considerably more larval blueback herring were collected in 1984. Larval fish were also collected earlier in 1984 than in 1983.

Discussion

Annual migrations of adult blueback herring in the Santee River are often characterized by several peaks in abundance (e.g., Bulak and Curtis 1977, Bulak et al. 1981, 1982). In 1984, CPM of adult herring peaked twice (8–15 Mar; 19 Mar–6 Apr). Eggs spawned during the first peak of adult herring would require approximately 4 days to hatch at ambient water temperatures (Morgan and Prince 1976) and 6 days of growth to reach 6.0 mm TL (Cianci 1969). Recently hatched larvae were first collected in 1984 on 23 March but did not peak until 14 April. If recently hatched herring larvae were spawned 6–10 days prior to collection, the first peak of adult herring (8–15 Mar 84) probably did not significantly contribute to the 14 April peak of larvae. The main contributor to the April peak in larval abundance was probably the second peak of adult herring. Bulak et al. (1981) reported peak commercial herring catches in 1981 on 13–14 March, 26 March, and 1–2 April, but recently hatched herring larvae were not collected in the Santee River until 4 April and did not peak until 12–18 April that same year (Meador et al. 1984). It appears, at least in some years, that the later peaks of adult herring were the main contributors to larval abundance in the Santee River.

Adult herring were less abundant in 1983 than in 1984, and only 1 major peak in adult herring abundance was observed in 1983. The lower number of adult herring in the Santee River in 1983 may be related to a reaction of adult herring to the inconsistent nature of discharges from Wilson Dam. A sudden decrease in adult herring CPM was observed shortly after a drastic increase in discharge from 16–19 March 1983. Adult herring CPM remained relatively low after this March decrease and gillnet samples were comprised mostly of fish caught heading downstream, apparently leaving the system. Downstream movement of the alewife, a closelyrelated alosid, is not at random but apparently triggered by increases in water flow (Huber 1978).

Similarly, in 1977, a relatively high commercial herring catch was recorded for the Santee River (Bulak and Curtis 1977) before discharge increased from 15 m^3/second on 29 March to 1053 m^3/second on 2 April (B. Inabinette, pers. commun.). Sudden changes in discharge such as in 1977 and 1983 may have caused adult herring to move downstream and away from spawning grounds. Consequently, fewer larval blueback herring would be expected to be present in the Santee River during those years the adult spawning migration is disrupted. Bulak et al. (1981, 1982) also noted that small percentages of recruits from the 1977-year class were collected in the Santee River in 1981 and 1982. On the other hand, Christie and Barwick (1984) observed that strong-year classes of blueback herring were produced in 1979 and 1980, when releases from Wilson Dam were relatively constant throughout much of the spawning season.

Sudden changes in discharge may affect water temperature (Petts 1984, Cushman 1985), an important environmental factor in the migration (Johnson et al. 1978) and spawning of blueback herring (Loesch and Lund 1977). The lowest minimum spawning temperature reported for blueback herring is 13°C (Hawkins 1979). Street (1970) reported that spawning began at 15°C in the Altamaha River, Georgia. Water temperature in the Santee River during 1983 fluctuated greatly, reaching 13°C first on 8 March but did not remain consistently above 15°C until after April 6. Temperature fluctuations of this type did not occur in 1984. In 1983, most adult herring were absent by 6 April when water temperatures were 15°C, and presumably, many had not spawned.

Rapid decreases in water temperature in the Santee River were often preceded by large increases in discharge from Wilson Dam (Fig. 2). Schooling behavior of adult alewives are affected by rapid changes in water temperature (Colby 1971). Although it may not be possible to separate the effect of varied water temperature and discharge upon the blueback herring in this study, the rapid change in discharge is arguably the underlying cause why water temperatures and possibly other unmeasured environmental parameters fluctuated erratically in the downstream portions of the Santee River.

Comparison of larval abundance between years of high and low discharge should be made with some caution, because larval numbers may be diluted by the high water volume. Differences in larval herring abundances between 1983 and 1984, however, do not appear to be due simply to differences in sampling efficiency (dilution) because water volumes (discharges) in the Santee River were similar, and the river remained within its banks in these 2 sample years.

This study, while unable to conclusively prove that discharge fluctuations during the blueback herring spawning season caused low larval herring abundance in the Santee River, should alert fishery biologists and hydroelectric and dam facility managers of the potential impacts of altered discharge on spawning blueback herring populations. Fluctuating discharges from Wilson Dam and the peaking hydroelectric plant located on the rediversion canal will undoubtedly exist in the future. Management plans for blueback herring populations in regulated rivers such as the Santee River should contain some restrictions for large and abrupt changes in discharge during the spawning season.

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