DPST-86-798
ECS-SR-27

DISTRIBUTION AND ABUNDANCE OF ICHTHYOPLANKTON IN THE MID-REACHES OF THE SAVANNAH RIVER AND SELECTED TRIBUTARIES

DPST-86-798
ECS-SR-27

Distribution and Abundance of Ichthyoplankton in the Mid-Reaches of the Savannah River and Selected Tributaries

Michael H. Paller
Bruce M. Saul
D. Vernon Osteen

Environmental & Chemical Sciences, Inc.
P. O. Box 1393
Aiken, South Carolina 29802

March 1986

This report, number ECS-SR-27, was prepared for
E. I. du Pont de Nemours & Company
Savannah River Laboratory
Aiken, South Carolina 29808

John B. Gladden
Program Advisor

by
Environmental & Chemical Sciences, Inc.
P. O. Box 1393
Aiken, South Carolina 29802

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

FIGURES

FIGURES (continued)

FIGURES (continued)

TABLES

TABLES (continued)

TABLES (continued)

TABLES (continued)

TABLES (continued)

EXECUTIVE SUMMARY

1. The 1985 Savannah River ichthyoplankton sampling program extended from February through July and included 21 river transects, two intake canals, five oxbows, and the mouths of 17 tributaries between River Mile (RM) 89.3 and RM 187.1. River transects, intake canals, and oxbows were sampled weekly. Creeks were sampled weekly when conditions permitted. This program was a continuation of monitoring begun during 1983 and employed the same sampling sites and methodologies except for the elimination of all sample sites (3 river transects, 11 creek mouths, and one oxbow) below RM 89.3.

2. The basic objective of this study was to assess spawning activity and ichthyoplankton distribution upstream and downstream from the Savannah River Plant (SRP) in order to evaluate the possible impact of existing and proposed thermal discharges and the removal of river water for secondary cooling of nuclear reactors. Special emphasis was placed on evaluating ichthyoplankton production in Steel Creek due to possible future impacts on this stream following the restart of L-Reactor.

3. A total of 19,926 fish larvae and 15,749 fish eggs were collected during 1985. As in previous years, the dominant group was the Clupeidae (65% of all ichthyoplankton), which included the anadromous blueback herring and American shad and the non-

anadromous threadfin and gizzard shad. Other abundant taxa were the sunfishes and spotted suckers. While important during 1983 and 1984, crappie and minnows were comparatively minor components of the ichthyoplankton during 1985.

4. The most abundant ichthyoplankton in Steel Creek were American shad, blueback herring, and darters. The high percentage and number of American shad and blueback herring indicate that the lower reaches of Steel Creek are a spawning area for these anadromous species. American shad and blueback herring have also been collected from Steel Creek during previous years, although American shad were more abundant during 1985 than in the previous years of this study.

5. An estimated 5.2 million fish larvae and eggs were transported from Steel Creek to the Savannah River during 1985. This was more than was transported from any other creek in the study area during 1985. Ichthyoplankton transport from all creeks was much lower during 1985 than during 1984 or 1983, possibly due to decreased creek discharges (79% lower during 1985 than 1984) and/or decreased spawning resulting from comparatively low water levels.

6. Temperatures in the mouth of Four Mile Creek were as much as 20°C higher than in the other creeks, due to reactor discharge. Ichthyoplankton were only collected from Four Mile

Creek during several brief periods of reactor outage when temperatures declined to near-ambient levels. These data indicate that ichthyoplankton are largely absent from the mouth of Four Mile Creek when the reactor is operating and water temperatures are high, but that fish will rapidly move into Four Mile Creek and begin spawning when the reactor shuts down.

7. Beaver Dam Creek, the other thermally-impacted SRP creek sampled during 1985, was approximately 1 - 8°C warmer than most of the creeks in the study area. Ichthyoplankton densities were unusually low in Beaver Dam Creek during May, June, and July. Temperatures often exceeded 30°C during these months.

8. Ichthyoplankton densities in the river were characterized by pronounced temporal changes. Mean ichthyoplankton density for the entire section of river under study was 0.3 organisms/1000 m^3 in ~~February, 18.2/1000 m^3 in March~~, 156.6/1000 m^3 in April, 139.4/1000 m^3 in May, 42.9/1000 m^3 in June, and 3.5/1000 m^3 in July. Statistical analysis indicated that most of the variability in ichthyoplankton density observed in this study was associated with sampling date, reflecting the influence of seasonal changes in temperature and photoperiod on spawning activity.

9. Larval densities in the river were generally similar near the top and bottom of the water column and across the channel; exceptions occurred at several transects where densities differed between banks. With the exception of RM 150.4, these differences were probably due to current patterns or to localized aggregations of spawning fish in favorable habitats.

10. At RM 150.4, larval densities were reduced near the South Carolina bank, where temperatures were elevated by thermal discharges from Four Mile Creek (RM 150.4). Reduced larval densities at RM 150.4 were most prominent during April and were due to decreases in the number of spotted sucker larvae; other taxa were not affected. These decreases were localized at RM 150.4 and not detectable farther downstream.

11. Unlike larval densities, egg densities were often greater near the bottom than near the surface. In addition, they were often unevenly distributed across the river channel. These distribution patterns were probably due to localized spawning and hydrological factors. The density of fish eggs was not reduced near the South Carolina bank at RM 150.4.

12. There are three important anadromous species that spawn in the Savannah River: American shad, striped bass, and blueback herring. American shad were collected in large numbers throughout the river and were far more abundant during 1985 than during 1983 and 1984. Striped bass were about as abundant during 1985 as during 1984, peaking in numbers near the SRP. Maximum blueback herring densities occurred in the upper portion of the study area during 1985 instead of in the lower portion of the study area as in 1983 and 1984. Blueback herring densities were fairly similar during 1984 and 1985, but during both years were low compared to 1983.

13. Two nonanadromous taxa, crappie and minnows, were much less abundant during 1985 than during earlier years, possibly because of unusually low river levels that eliminated floodplain spawning sites for these species. Floodplain spawning sites are not important for species such as American shad and striped bass, which spawn in the river channel.

14. Spawning trends and ichthyoplankton densities in the five oxbows sampled during 1985 were generally comparable to those in the river. The only exception was an oxbow at RM 100.2 that consistently had much higher densities than the river. Reasons for the apparent productivity of this oxbow are unknown at present. Gizzard and threadfin shad were the dominant ichthyoplankton in the oxbows.

15. Diel collections from the Savannah River and intake canals during March, April, May, and June indicated significantly higher ichthyoplankton densities during the night than during the day. While this pattern was also observed during 1982 and 1984, day - night differences were more consistent during 1985. In 1983, the diel collections indicated higher densities during the day, due to exceptionally large numbers of threadfin and gizzard shad larvae.

16. On the basis of ichthyoplankton samples taken during daylight hours, an estimated 26.0×10^6 ichthyoplankton (10.8×10^6 larvae and 15.1×10^6 eggs) were entrained during 1985. This is approximately 12.1% of the total number of ichthyoplankton that drifted past the SRP pumphouses.

17. Total ichthyoplankton entrainment during 1985 (26.0×10^6) was fairly similar to that in 1977 (26.4×10^6) and 1984 (23.4×10^6), but less than that in 1982 (36.0×10^6) and 1983 (37.2×10^6).

1.0 INTRODUCTION

The Savannah River watershed includes western South Carolina, eastern Georgia, and a small portion of southwestern North Carolina. It is formed by the confluence of the Tugaloo and Seneca rivers in northeast Georgia and flows southeast through the Piedmont and Coastal Plain to the Atlantic Ocean. In its mid- and lower reaches, it is broad with extensive floodplain swamps and numerous tributaries. The substrate consists of various combinations of silt, sand, and clay. The river is influenced by dredging, sewage discharge, and industrial inputs, and water flow is controlled by a system of reservoirs, locks, and dams.

In 1951, the Savannah River Plant (SRP) was established near Aiken, South Carolina, to produce nuclear materials for national defense. During the time period covered in this report, the SRP was operating three nuclear reactors and a coal-fired power plant. C- and K-Reactors are cooled by water pumped from the Savannah River and returned to the river through Four Mile Creek or the Pen Branch/Steel Creek system, respectively. Cooling water pumped from the Savannah River for the power plant returns to the river through Beaver Dam Creek. Thermal effluents discharged into these creeks flow through a floodplain swamp before reentering the Savannah River through breaks in a natural levee separating the swamp from the river. P-Reactor utilizes a large, man-made cooling pond on the upper reaches of Lower Three Runs Creek and requires only make-up water from the Savannah River to replace losses by seepage and evaporation. Prior to being placed on stand-by in 1968, L-Reactor discharged cooling water into Steel Creek, which flows into the Savannah River near the southern boundary of the SRP. The data presented in this report was collected prior to the October 1985 re-start of L-Reactor.

The thermal plumes created in the Savannah River by SRP effluents vary in size and temperature as a result of changes in reactor operation, Savannah River water level, and season of the year. When water levels are low, effluents from the thermal creeks discharge directly into the river, producing plumes that follow the South Carolina shore. Thermal infrared surveys taken in August 1982 indicate that during midsummer the plume from Four Mile Creek may be more than 10^{o}C above ambient at the egress from the swamp (Bristow and Doak 1983), but that the plume dissipates quickly, due to dilution by the much larger Savannah River. The August infrared survey indicated that the temperature of the Four Mile Creek plume had dropped to approximately 2^{o}C above ambient at 400 m downstream of the discharge point. During colder months, however, the 2^{o}C isotherm extends farther downstream because of the greater temperature difference between the creek and river waters.

When water level in the Savannah River is high enough to inundate the SRP floodplain swamp, there are no thermal plumes discharged directly into the river. Under flood conditions, the creeks discharge into the flooded swamp, and the water is channeled downstream along the upland bank of the swamp by the river overflow. Dilution and cooling occur in the floodplain swamp before the SRP effluent is discharged into the main channel (Shines and Tinney 1983).

Because the Savannah River and its tributaries support a variety of fishes, there is concern about the effects of SRP thermal discharges on onsite and offsite fish populations. Reproductive processes are the most likely aspect of fish life histories to be disrupted by SRP activities, due to the correlation of temperature with the initiation of spawning (Wrenn 1984; Nikolsky 1963) and the vulnerability of passively drifting fish eggs and larvae (collectively termed ichthyoplankton) to entrainment. Of particular interest are possible impacts on anadromous fishes -- American shad, striped bass, and blueback herring -- which support recreational and commercial fisheries in the Savannah River during their spawning migration from the Atlantic Ocean. However, thermal blockage of upstream spawning sites to migratory fishes does not occur (ECS 1983; Paller et al. 1984), since thermal plumes from the SRP do not extend completely across the river (NUS 1982).

Onsite spawning areas may be impacted by reactor operations. Of particular interest are any effects on the spawning areas in Steel Creek due to the re-start of L-Reactor. Steel Creek currently supports a diverse community of resident fishes, and its lower reaches are used as a spawning area for several anadromous species (Paller et al. 1985). Previous studies indicate that spawning sites in Steel Creek contribute large numbers of ichthyoplankton to the Savannah River (Paller et al. 1984, 1985).

Previous ichthyoplankton studies in regions of the Savannah River near the SRP were conducted by McFarlane et al. (1978) to estimate entrainment at the SRP pumphouses. More extensive studies were undertaken in 1982 by Environmental and Chemical Sciences, Inc. (ECS) under contract to Savannah River Laboratory (SRL) to assess both entrainment losses and spatial and temporal ichthyoplankton distribution in the region of the SRP. These studies were expanded during 1983 and 1984 to include a 157.5 mile (253.4 km) section of the Savannah River and associated tributaries upstream and downstream from the SRP (Paller et al. 1984). Some of the more important findings of the 1983 and 1984 studies were that

1. Most species (both anadromous and nonanadromous) spawning near the SRP also had important spawning areas elsewhere in the river,

2. There were no obvious changes in ichthyoplankton density near the thermal creek mouths, suggesting no unusual mortality of ichthyoplankton,

3. Ichthyoplankton entrained at the SRP pumphouses constituted approximately 9.3% and 8.3% of all ichthyoplankton drifting past the SRP during 1983 and 1984, respectively,

4. Many creeks, especially those in the downstream half of the study area, exported large amounts of ichthyoplankton into the Savannah River, and

5. Steel Creek exported more ichthyoplankton to the Savannah River than any other creek in the upstream half of the study area.

Included in this report are the results of the 1985 Savannah River ichthyoplankton monitoring program. The 1985 program was a continuation of the 1983 and 1984 program and -- except for the elimination of 3 river transects, 11 creek mouths and 1 oxbow from the sampling program and the addition of one river transect to the program -- incorporated the same sampling sites and methodologies. The objectives of this study were

1. To determine the density and distribution of ichthyoplankton at designated locations in the Savannah River, tributaries, and intake canals of the SRP between RM 187.1 (the New Savannah Bluff Lock and Dam) and RM 89.3 (below Buck Creek);

2. To evaluate the river and creeks upstream, adjacent to, and downstream of the SRP for their relative contribution to the ichthyoplankton community of the Savannah River system;

3. To provide data to evaluate the impact of the present and proposed cooling water intake rates on fish eggs and larvae;

4. To provide data to evaluate the impact of existing and proposed thermal discharges to the river; and

5. To provide information on the magnitude of yearly variations in ichthyoplankton density and abundance in the mid- and lower reaches of the Savannah River and its tributaries.

The results section of this report is subdivided into Ichthyoplankton Distribution, Entrainment, and Diurnal Studies. Ichthyoplankton Distribution discusses the abundance, time of occurrence, and spatial distribution of ichthyoplankton in the Savannah River, tributaries, and associated river oxbows. Entrainment reports the estimation of ichthyoplankton losses caused by water withdrawal at the SRP intake structures and aspects of ichthyoplankton distribution in the intake canals and nearby river transects that affect these losses. Diurnal Studies presents the results of special sampling efforts designed to assess the magnitude of fluctuations in ichthyoplankton density in the Savannah River over a 24 h period.

2.0 METHODS AND MATERIALS

2.1 SAMPLING STATION LOCATIONS

Twenty-one transects across the river, 2 intake canals, 5 river oxbows, and 17 creeks were included in the 1985 ichthyoplankton sampling program. All sample stations were identical to those sampled during 1984 except for the deletion of eight creeks, one river oxbow, and three river transects and the addition of one river transect at RM 145.7 to more closely monitor ichthyoplankton densities near the SRP. In addition, three creeks scheduled for sampling during 1985 (Lower Boggy Gut, RM 141.3; High, RM 171.6, and Pine, RM 180.1) could not be sampled because of low water. The study area was located between RM 89.3 and 187.1, from just below Buck Creek to just below the New Savannah Bluff Lock and Dam (Figure 2-1). This distance represents a decrease from 1984, when the study area included an additional 59.7 miles of river (from RM 29.6 - 89.3). All river, creek, and oxbow sample stations eliminated during 1985 were in the reach between RM 29.6 and 89.3.

For descriptive purposes, the river was divided into three sections: the upper farfield, upstream of the SRP and including three river transects between RM 166.6 and 187.1; the nearfield, adjacent to the SRP and including 14 transects and two intake canals between RM 128.9 and 157.3; and the lower farfield, downstream of the SRP and including 10 transects between RM 89.3

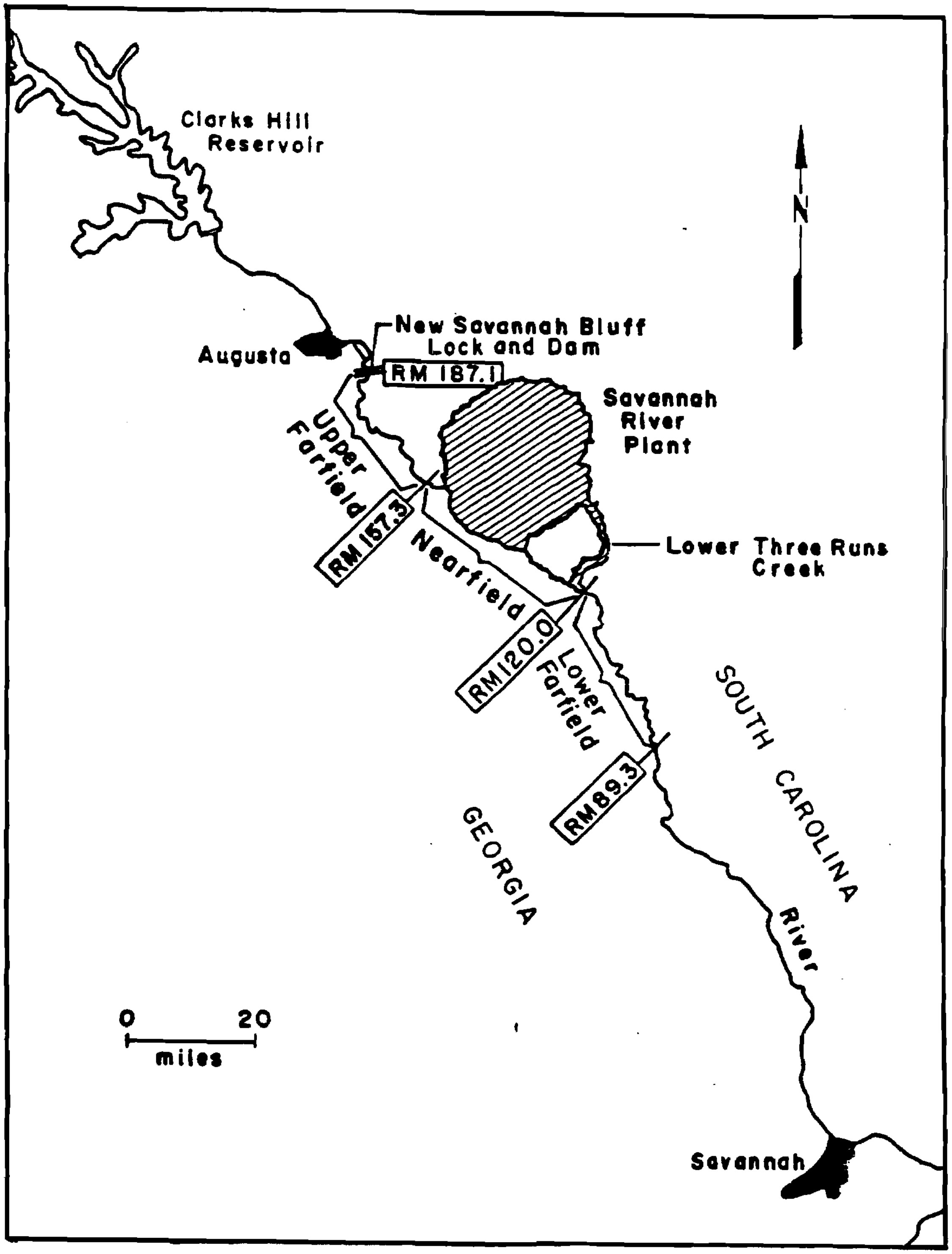


Figure 2-1. Map of the Savannah River showing the location of the Savannah River Plant, lower farfield, nearfield, and upper farfield sections of the river. February - July 1985.

and 120.0 (Table 2-1). Transects in the upper farfield and lower farfield were situated at approximate 10-mile intervals, while transects in the nearfield were more closely spaced to monitor phenomena associated with SRP activity. Creek sample stations were located in all three river study sections, with 6 in the upper farfield, 7 in the nearfield, and 4 in the lower farfield (Table 2-1). There were two oxbows in the upper farfield, two in the nearfield, and one in the lower farfield.

Each of the river transects was sampled near the South Carolina shore, mid-river, and near the Georgia shore. The intake canal stations were sampled near both shores and in mid-canal. Creeks and oxbows were sampled only in mid-channel, within 20 m of their mouths. If water depth exceeded two meters, both surface and bottom samples were taken. All samples were taken in duplicate.

2.2 SAMPLING SCHEDULES

The 1985 collecting protocol consisted of sampling all stations weekly from early February 1985 through July 1985, although there were weeks when some of the creeks could not be sampled because high river levels reversed their flow (i.e., from the river into the creeks) or because low water precluded effective sampling. Since ichthyoplankton abundance can vary within a short time frame (ECS 1982), all nearfield ichthyoplankton collections were taken on the same day to reduce the potential variation of ichthyoplankton densities between sample dates. Because of the

Table 2-1. Sampling station locations for the Savannah River ichthyoplankton monitoring program. February - July 1985.

River Mile	Sampling station location
River transect	
	Upper Farfield
187.1	River transect above Savannah River Plant
176.0	River transect above Savannah River Plant
166.6	River transect above Savannah River Plant
	Nearfield
157.3	Above 1G canal
157.0	Below 1G canal
155.4	Above 3G canal
155.2	Below 5G pumphouse
152.2	Above Beaver Dam Creek
152.0	Below Beaver Dam Creek
150.8	Above Four Mile Creek
150.4	Below Four Mile Creek
145.7	Recovery transect below Four Mile Creek
141.7	Above Steel Creek
141.5	Below Steel Creel
137.7	Recovery transect below Steel Creek
129.1	Above Lower Three Runs Creek
128.9	Below Lower Three Runs Creek
	Lower Farfield
120.0	River transect below Savannah River Plant
110.0	River transect below Savannah River Plant
97.5	River transect below Savannah River Plant
89.3	River transect below Savannah River Plant
Creek transect	
183.3	Spirit Creek
180.1	Pine Creek
176.1	Hollow Creek
171.6	High Bank Creek
164.2	McBean Creek
162.2	Upper Boggy Gut
157.2	Upper Three Runs Creek[a]
152.1	Beaver Dam Creek[a]
150.6	Four Mile Creek[a]
141.6	Steel Creek[a]
141.3	Lower Boggy Gut
133.5	Sweetwater Creek
129.0	Lower Three Runs Creek[a]

[a]Located on the Savannah River Plant.

Table 2-1. (continued). Sampling station locations for the Savannah River ichthyoplankton monitoring program. February - July 1985.

River Mile	Sampling station location
Creek transect	
126.5	Smith Lake Creek
109.0	The Gaul
97.6	Briar Creek
92.6	Buck Creek
Intake transect	
157.1	1G Canal[a]
155.3	3G Canal[a]
Oxbows	
183.0	Fritz Cut
167.4	Unnamed
156.7	Unnamed
153.2	Unnamed
100.2	Miller's Old Lake

[a]Located on the Savannah River Plant.

distances involved, upper farfield and lower farfield areas of the river could not be sampled on the same day, but were sampled within two days of the nearfield sampling.

In March, April, May, and June, regular ichthyoplankton collections were supplemented by 24 h samplings at RM 157.3, 157.1, 157.0, 155.4, 155.3, and 155.2 to obtain data on potential diel variation in ichthyoplankton abundance near the SRP cooling water intakes. The diel samples were collected every 6 h, with collection times falling between 0600-1200, 1200-1800, 1800-2400, 2400-0600 h. A 5 min sampling period enabled collections to be made at all transects within the allotted 6 h period and provided two day and two night samples for each location.

To obtain further information on diel variations in ichthyoplankton density, collections were made twice daily at RM 141.7 on 11 dates in April, May, June, and July, with the first sample collected in the morning and the second sample collected in the afternoon. This procedure, done weekly from April - July in conjuction with regular sampling, was conducted to help explain ichthyoplankton density peaks observed in the region of RM 141.7 during 1983 and 1984 that may have been time related.

2.3. FIELD PROCEDURES

Ichthyoplankton collections were made with two 0.5 m diameter 505μ mesh plankton nets mounted side by side in a common frame. In the river, samples were usually taken by suspending the nets in the current from an anchored boat. Each conical net was fitted with a one-liter plastic bottle to hold the concentrated volume of organisms and detritus filtered from the water. The bottle was labeled with the sampling location, depth, date, and replicate number. The label was also coded to the field data book, where additional information about the collecting conditions was recorded. A General Oceanics Model 2030 digital flow meter was placed in the center of the mouth of each net to record the volume of water filtered for each sample. Low speed impellers were used at current velocities under 0.3 m/s, and high speed impellers were used at higher current velocities. The collecting duration was timed so that approximately 50 m^3 of water were filtered for each sample. For surface collections, the center of the nets was maintained approximately 0.5 m below the surface. For bottom samples, the nets were weighted so that a sample was taken approximately 0.5 m above the substrate.

In the intake canals, the current velocity was too low (< 0.1 m/s) for an adequate sample to be collected from an anchored boat. Instead, samples were collected by towing the nets for approximately three-fourths the length of the canal. The length of the tow was adjusted so that approximately 50 m^3 of water was filtered. In general, the velocity through the net was maintained at less than 1 m/s. Parallel surface tows were made close to each bank and down the center of the canal, and a bottom collection was made down the center of the canal. Bottom collections were not made along the sides of the canal, because the water was too shallow and the bottom topography too variable.

Creeks and oxbows with adequate flow were sampled by set net. Others, with low flow rates, were sampled by towing the net. A few creeks were blocked by fallen trees and could only be sampled by setting the nets for a long period of time. Creeks and oxbows deeper than 2 m were sampled at surface and bottom whenever possible.

At the end of each collecting period, the nets were retrieved and rinsed to flush the contents into the collecting bottles. Enough concentrated buffered (pH 7) formalin was added to the bottles to bring the formalin concentration to approximately 5%. Each bottle was then sealed and stored for return to the laboratory. The formalin contained 0.2 g/L Eosin red and 0.2 g/L Biebrich scarlet stains to color the organisms for easier separation from detritus.

2.4 PHYSICAL AND CHEMICAL DATA COLLECTION PROCEDURES

Measurements of surface pH, conductivity, dissolved oxygen, temperature, flow velocity, and alkalinity were made at each transect concurrently with each ichthyoplankton sample.

2.4.1 Water Temperature

Water temperature was measured with a Hydrolab Model VI, a Horiba Model U7, a YSI Model 33 S-C-T Meter, or a YSI Model 54 Oxygen Meter. Surface temperatures were measured at all sample sites, and bottom temperatures were measured where bottom ichthyoplankton samples were taken. Although the instrument used varied during the project, each was periodically checked against an NBS calibrated mercury thermometer, and all data are considered comparable.

2.4.2 Water Flow Velocity

Water current velocity was measured with a General Oceanics Model 2030 current meter or a General Oceanics remote reading flow meter. When the Model 2030 was used, the meter was suspended about 0.5 m from the surface for 100 s. When the remote reading model was used, the sensor was lowered to approximately 0.5 m below the surface and the velocity was read directly from the meter control box. Low speed impellers were used at current velocities under 0.3 m/s. High speed impellers were used at higher current velocities. Velocities were calculated utilizing calibration constants supplied by General Oceanics. Meter accuracy was periodically checked by comparisons with factory-calibrated flowmeters. Current velocity was measured in the center and ear each bank in both the river and the creeks.

2.4.3 Alkalinity

Alkalinity determinations were made in the laboratory on sub-surface samples packed in ice in the field and kept on ice until processed. Sample volumes of 200 ml were titrated with 0.02 N H_2SO_4 to a pH of 4.3 to 4.7; the acid volume and exact pH were recorded; additional acid was added to lwer the pH exactly 0.3 units; and the final acid volume recorded (APHA, 1980; Method 403 for low alkalinity sample). An Orion Model 407 A Specific Ion

Meter and a Beckman combination electrode were used for the titrations. The meter system was standardized in buffers of pH 7 and pH 4 before use.

2.4.4 Dissolved Oxygen

Dissolved oxygen was measured with a Hydrolab Model VI or a Horiba Model U7. Measurements were taken by lowering the sonde to approximately 0.5 m below the surface, starting the circulating motor, and recording the readings after a minimum delay of 5 min. Instruments were calibrated at the beginning of each day by submerging them in air-saturated water.

2.4.5 pH

Both the Hydrolab and Horiba water quality monitors had pH functions that permitted direct measurement of water pH in the field. The pH systems of both monitors were calibrated in the laboratory prior to each day's use, following the procedures given by the instrument's manufacturer. The pH was measured approximately 0.5 m below the surface.

2.4.6 Specific Conductance

Specific conductance was measured with a Hydrolab Model VI or a YSI Model 33 S-C-T Meter. Performance of the instrument was checked daily with KCl solutions. The specific conductance measurement system on the Horiba Model U7 was ineffective because of the low conductance values in the Savannah River.

2.4.7 Creek Morphometry

The cross-sectional area of each creek was measured at the location where ichthyoplankton samples were taken. Data from each creek included depths at 4 to 10 equally spaced intervals on a transect across the creek, width of the creek at the water line, width of the creek at the top of the banks, and bank height (i.e., height from water line to top of banks). These data were used to generate a cross-sectional depth profile of each creek. Maximum depth measurements at each creek mouth were taken with each ichthyoplankton sample. The maximum-depth readings were used to adjust the depth profiles to changes in water level. The cross-sectional area of each creek on each sample date was calculated by taking the average depth between each pair of depth readings, multiplying the average depth times the distance (m) between the depth readings, and summing the areas calculated across the creek. Calculated cross-sectional areas were multiplied by mean current velocity to determine the discharge (m^3/s) from each creek on each sample date. Mean current velocity was calculated from current readings taken at three equally spaced intervals across each creek and at near-top and near-bottom locations (when depth exceeded 2 m) or at mid-depth (when depth was less than 2 m).

2.5 LABORATORY PROCEDURES

Immediately after the samples were returned to the laboratory, they were logged and checked against the field data book to ensure that the collection was complete. Before a sample was processed, formalin was removed by placing the sample in a 505 μ mesh strainer and rinsing the retained material several times with water.

Fish eggs and larvae were sorted from the detritus, using a stereo microscope, and placed in ethanol solution. An alcohol-proof label identifying the sample and the sorter was maintained with the sample at all times. After analysis, the organisms from each sample were permanently stored. The detritus was either saved for the quality assurance checks or discarded (Paller et al. 1984). All data were recorded on bench sheets, which were maintained in a central file as part of the overall quality assurance program.

2.6 TAXONOMIC PROCEDURES

Ichthyoplankton samples were examined under a stereomicroscope and identified to the lowest practical taxon, using taxonomic keys by Geen et al. (1966), Mansuetti and Hardy (1967), Hogue et al. (1976), Jones et al. (1978), and Wang and Kernehan (1979). Identifications of particularly difficult or important taxa, such as the shortnose sturgeon, the perch/darter complex, and some less well-known sunfishes, were verified by Darrel E. Snyder of the Larval Fish Laboratory at Colorado State University. Nomenclature throughout this report follows Robins et al. (1980).

Blueback herring (Alosa aestivalis) and threadfin or gizzard shad (Dorosoma spp.) larvae are easily distinguished while they have yolk sacs, but are difficult to differentiate after the yolk sack has been absorbed or if the specimen has been damaged. When possible, these larvae were identified to genus or species; when positive identification was impossible, they were categorized as unidentified clupeids. "Unidentified clupeids" also includes small numbers of other clupeid species. Numerous species of the minnow family (Cyprinidae) occur in the Savannah River. These fishes are difficult to differentiate even as adults, and the larval forms of many species have not been described. For this study, the only taxonomic distinction made within this group was to place carp (Cyprinus carpio) greater than 6 mm in length into a separage category. The category "unidentified larvae" generally included all larvae too damaged to identify reliably.

All fish eggs collected were assigned to one of the following categories: American shad (Alosa sapidissima), blueback herring (Alosa aestivalis), striped bass (Morone saxatilis), yellow perch (Perca flavescens), darter (Percidae), threadfin or gizzard shad (Dorosoma spp.), minnow (Cyprinidae), or "others." More refined identifications were not attempted because of the difficulty in differentiating the eggs of most species.

2.7 STATISTICAL PROCEDURES

Densities of fish eggs and larvae were calculated by dividing the number of larvae and eggs captured in each net by the volume of water filtered through the net. The resulting number was multiplied by 1000 to give ichthyoplankton density as number of organisms/1000 m^3. Ichthyoplankton densities were compared between transects, locations across the channel, and location in the water column, using analysis of variance (general linear model procedure, SAS 1982), Scheffe's tests, and t-tests. In addition to these tests, Pearson Product Moment correlation coefficients were calculated between mean monthly ichthyoplankton density and mean monthly temperature.

Prior to statistical testing, the distribution of ichthyoplankton densities was evaluated using Taylor's Power Law (Greene 1979). The results of the evaluation indicated that means and variances were correlated and that a log transformation was needed to meet the assumption of analysis of variance for homogeneity of variance. The constant used in this transformation was +10 (i.e., $X' = \log_{10} (x = 10)$ rather than the more commonly used 0.5 (Sokal and Rohlf 1981), since it produced a closer approximation to the normal distribution (William Feller, E. I. du Pont de Nemours statistician, personal communication).

While log-transformed data was employed in all statistical tests used in this report, arithmetic means are generally presented in the texts and tables. The decision to use arithmetic means as the basic measure of central tendency was based on several considerations. First, the sample arithmetic mean is an unbiased estimator of the population mean even when the distribution is non-normal (Gilbert 1983). Second, when sample size is large, as is the case for many of the comparisons made in this study, the sample mean is approximately normally distributed regardless of the form of the underlying distribution (i.e., central limit theorem; Sokal and Rohlf 1981). Third, one value of the geometric mean, another commonly used measure of central tendency, can be influenced by sample size (Gilbert 1983). Fourth, arithmetic means are commonly used in studies of ichthyoplankton; hence, the use of arithmetic means in this study facilitates comparisons with prior work. Fifth, most readers are familiar with arithmetic mean; thus, the use of arithmetic means should make this document more understandable to an expected readership of diverse background. There are several places in the following pages where statistical results are best understood when other measures of central tendency are presented along with the arithmetic mean. In such cases both measures are presented.

Further evaluation of test designs will be provided at appropriate places in the report. The general approach used in statistical testing has been to employ a variety of tests to assess different aspects of ichthyoplankton distribution at different levels of resolution. This strategy is intended both to detect the presence of anomalies in distribution and to provide some perspective on the relative magnitude and importance of these anomalies.

2.8 TRANSPORT CALCULATIONS

The number of ichthyoplankton transported from each creek into the river on each sample date was calculated by multiplying ichthyoplankton density (no./m^3) times creek discharge (m^3/s). The cumulative number transported from each creek over the entire February - July sample period was calculated by a numerical integration technique that consisted of averaging ichthyoplankton transport (no./s) between each pair of consecutive sample dates, multiplying the mean by the time (s) between collection dates, and summing the values for all intervals.

The number of ichthyoplankton transported past each river transect (no./s) on each sample date was calculated by multiplying ichthyoplankton density at that transect (no./m^3) times river discharge (m^3/s) on the same date as measured at the nearest USGS gauging station. Discharges recorded at Augusta, GA (RM 187.4), were used when calculating transport at RM 187.1 through 176.0; discharges recorded at Jackson, SC (RM 156.8), were used when calculating transport at RM 166.6 through 141.5; and discharges recorded at Highway 301 (RM 119.7) were used when calculating transport at RM 137.7 - 89.3. The total number of ichthyoplankton transported past each river transect over the entire February - July sample period was calculated as described for the creeks. Program listings for all computer-generated analyses are presented in Appendix 1.

The transport values presented in this paper should be regarded as rough approximations, since detailed hydrological models are unavailable for the Savannah River and its tributary creeks, since ichthyoplankton sampling was conducted only once a week and since ichthyoplankton data typically exhibit high variability, as they did in this study. The primary function of the transport values is to provide a common basis for evaluating the number of ichthyoplankton contributed to the river by a variety of creeks that differ in size and discharge by several orders of magnitude. A second and related function is to provide a common basis for comparing the amount of ichthyoplankton transported into the river from the creeks with the amount already present in the river. Both of these issues must be considered in determining the relative importance of Steel Creek as a spawning area; however, neither can be answered using ichthyoplankton-density information alone.

3.0 RESULTS AND DISCUSSION

3.1 ICHTHYOPLANKTON DISTRIBUTION

The abundance of ichthyoplankton is one measure of the reproductive success of fishes, and dense concentrations of ichthyoplankton may indicate important spawning areas. In addition, ichthyoplankton are particularly vulnerable to certain types of environmental impact, especially those involving water withdrawals (Hocutt et al. 1980). For these and related reasons, ichthyoplankton monitoring is often included in environmental studies such as those that have been done on the Connecticut River (Merriman and Thorpe 1976), the Missouri River (Hesse et al. 1982), and the Susquehanna River (Lathrop 1982). The present study includes a 97.8-mile reach of the Savannah River between river miles (RM) 89.3 and 187.1, 17 Savannah River tributaries, 5 river oxbows, and 2 intake canals. The report's primary emphasis is to describe and interpret aspects of ichthyoplankton abundance and distribution with particular reference to phenomena that might stem from SRP operations or that might be affected by future SRP operations. Special emphasis has been placed on evaluating ichthyoplankton production in Steel Creek because of possible impacts on this stream following the re-start of L-Reactor.

A total of 19,926 fish larvae and 15,749 fish eggs were collected from the Savannah River, Savannah River oxbows, Savannah River tributaries, and SRP intake canals (Table 3-1; Appendix 2). The dominant larvae were gizzard and/or threadfin shad (35.5%), sunfish (unidentified sunfish and *Lepomis* spp.; 13.2%), unidentified clupeids (12.7%), spotted sucker (10.7%), carp (5.6%) and blueback herring (5.4%). The dominant eggs were those of the American shad (73.0%) and striped bass (7.2%). Both American shad and striped bass produce drifting eggs that have a higher probability of capture by ichthyoplankton nets than the adhesive and/or demersal eggs of most other species.

3.1.1 Creek Ichthyoplankton

3.1.1.1 Ichthyoplankton Densities in Savannah River Tributary Creeks

This section is subdivided into a general treatment of ichthyoplankton abundance in all tributaries (3.1.1.1), a discussion of ichthyoplankton transport from creeks into the river (3.1.1.2), and a detailed examination of ichthyoplankton abundance in the creeks on the SRP (3.1.1.3).

The 14 creeks sampled during 1985 (Table 3-2) ranged from small intermittent streams to major tributaries. The mean February - July discharge of the creeks varied from 0.0 m^3/s at Buck Creek, The Gaul, and Upper Boggy Gut Creek to 15.1 m^3/sec at Briar Creek (Table 3-3). Discharge from most of the creeks was highly variable. The average discharge of the 14 creeks sampled during

Table 3-1. Ichthyoplankton taxa collected from the Savannah River, tributaries, oxbows, and the Savannah River Plant intake canals. The study area was between RM 89.3 and 187.1 and included 22 river transects, 2 intake canals, the mouths of 14 tributary creeks, and 5 oxbows. February - July 1985.

Taxa	Number	Percent
Larvae		
sturgeon	6	<0.1
gar	1	<0.1
unid. Clupeidae	2522	12.7
blueback herring	1076	5.4
American shad	361	1.8
gizzard and/or threadfin shad	7070	35.5
mudminnow	1	<0.1
pickerel	8	0.1
needlefish	2	<0.1
minnow (family Cyprinidae)	856	4.3
carp	1109	5.6
unid. suckers	111	0.6
spotted sucker	2142	10.7
catfish and/or bullhead	3	<0.1
swampfish	1	<0.1
pirate perch	17	0.1
topminnow	4	<0.1
mosquitofish	7	<0.1
brook silverside	144	0.7
striped bass	134	0.7
unid. sunfish	298	1.5
sunfish (*Lepomis*)	2337	11.7
crappie	373	1.9
darter	675	3.4
yellow perch	387	1.9
unid. larvae	281	1.4
Totals	19,926	100.0
Eggs		
blueback herring	491	3.1
American shad	11,494	73.0
gizzard and/or threadfin shad	339	2.2
minnow	39	0.2
striped bass	1132	7.2
yellow perch	48	0.3
other eggs	2206	14.0
Totals	15,749	100.0

NOTE: RIVIC1 and RIVIC2 were used to compute the data presented in the table.

Table 3-2. Chemical parameters (mean and range) in the mouths of selected Savannah River tributaries. February - July 1985.

Creek (RM)	Temperature (^{o}C)	Dissolved oxygen (mg/L)	Conductivity (μS/cm)[b]	Alkalinity (mgCaCO$_3$/L)	pH	Number of dates sampled
Buck (92.6)	19.2 (6.3 - 28.2)	5.9 (3.0 - 9.2)	157.7 (67.0 - 260.0)	47.3 (6.3 - 74.5)	6.7 (4.7 - 8.3)	23
Briar (97.6)	19.3 (5.2 - 30.5)	7.1 (5.2 - 9.4)	95.4 (51.0 - 134.0)	23.3 (5.8 - 29.0)	6.6 (5.2 - 7.9)	26
The Gaul (109.0)	10.9 (4.0 - 17.8)	5.9 (5.5 - 6.5)	69.6 (63.0 - 78.0)	13.0 (8.3 - 17.0)	4.9 (3.9 - 6.2)	3
Smith Lake (126.5)	17.6 (6.0 - 27.0)	6.1 (3.5 - 9.7)	93.5 (28.0 - 178.0)	31.9 (15.8 - 52.8)	6.5 (3.7 - 8.6)	26
Lower Three Runs (129.0)[a]	18.3 (8.0 - 26.1)	7.2 (5.4 - 9.7)	93.9 (64.0 - 124.0)	33.6 (20.5 - 43.0)	6.4 (4.1 - 7.3)	23
Sweetwater (133.5)	17.1 (7.0 - 25.3)	6.1 (4.6 - 10.5)	66.0 (33.0 - 84.0)	19.0 (13.0 - 24.3)	6.3 (4.2 - 7.3)	20
Steel (141.6)	19.1 (6.0 - 27.0)	6.5 (2.7 - 10.4)	80.6 (34.0 - 108.0)	18.7 (8.0 - 23.5)	6.2 (4.2 - 7.3)	26
Four Mile (150.6)	32.7 (11.0 - 40.5)	5.6 (3.6 - 8.3)	79.2 (42.0 - 94.0)	14.0 (9.3 - 22.7)	6.6 (5.7 - 7.5)	25
Beaver Dam (152.1)	25.7 (15.5 - 33.0)	5.4 (4.0 - 7.2)	88.5 (24.0 - 125.0)	16.3 (11.8 - 18.5)	6.4 (4.9 - 7.6)	25
Upper Three Runs (157.2)	17.0 (8.0 - 24.9)	7.3 (5.2 - 9.3)	23.8 (17.0 - 61.0)[b]	3.5 (1.0 - 6.0)	6.3 (5.2 - 7.6)	25
Upper Boggy Gut (162.2)	8.0 (8.0 - 8.0)	6.9 (6.8 - 6.9)	56.0 (40.0 - 72.0)	16.0 (16.0 - 16.0)	6.1 (6.0 - 6.1)	1
McBean (164.2)	19.1 (6.5 - 28.1)	6.7 (3.6 - 9.6)	53.9 (45.0 - 66.0)	17.9 (11.0 - 21.3)	6.6 (4.7 - 9.3)	24
Hollow (176.1)	18.1 (6.6 - 26.2)	7.2 (3.1 - 10.2)	18.3 (11.0 - 80.0)	3.9 (0.3 - 39.0)	6.1 (4.8 - 9.0)	26
Spirit (183.3)	18.9 (6.0 - 28.0)	6.6 (4.4 - 10.6)	45.7 (29.0 - 64.0)	5.6 (2.3 - 18.3)	6.2 (5.0 - 8.3)	26

NOTE: RIVIC16 was used to compute the data presented in this table.

[a]Underscores indicate creeks draining the SRP.
[b]Equivalent to μmho used in earlier reports.

Table 3-3. Discharge and current in Savannah River tributaries. February - July 1985.

Creek (RM)	Dates sampled[a]	Mean discharge (range) m^3/sec	Mean current (range) m/sec	Width[b] (m)
Buck (92.6)	23	0.0(0.0- 0.0)	0.0(0.0-0.0)	23
Briar (97.6)	26	15.1(0.7-125.8)	0.3(0.1-0.9)	28
The Gaul (109.0)	3	0.0(0.0- 0.0)	0.0(0.0-0.0)	5
Smith Lake (126.5)	26	3.7(0.0- 50.0)	0.1(0.0-0.7)	30
Lower Three Runs (129.0)	23	1.2(0.0- 3.1)	0.1(0.0-0.4)	16
Sweetwater (133.5)	20	1.2(0.0- 2.8)	<0.1(0.0-0.4)	17
Steel (141.6)	26	8.5(0.9- 29.3)	0.3(0.1-0.5)	26
Four Mile (150.6)	25	1.2(0.0- 4.3)	0.2(0.0-0.4)	9
Beaver Dam (152.1)	25	3.8(0.0- 11.9)	0.4(0.0-0.8)	12
Upper Three Runs (157.2)	25	2.8(0.0- 16.8)	0.1(0.0-0.4)	28
Upper Boggy Gut (162.2)	1	0.0(0.0- 0.0)	0.0(0.0-0.0)	9
McBean (164.2)	24	1.3(0.0- 3.1)	0.2(0.0-0.4)	11
Hollow (176.1)	26	2.4(0.6- 7.2)	0.2(0.1-0.5)	13
Spirit (183.3)	26	1.5(0.5- 4.8)	0.2(0.1-0.3)	9

[a]Some creeks were not sampled consistently because high water levels reversed their direction of flow or because low water precluded effective sampling. Mean discharges and flow rates were calculated only from dates on which samples were taken.

[b]Width at low water.

1985 was 3.1 m^3/sec compared to 10.5 m^3/sec during 1984 and 21.3 m^3/sec during 1983 for the same 14 creeks (Paller et al. 1984, 1985).

The mean temperature in the non-thermal creeks (i.e., all creeks except Four Mile and Beaver Dam) varied from 8.0 to 19.3°C (Table 3-2). The low mean temperatures recorded for Upper Boggy Gut (8°C) and The Gaul (10.9°C) were due to the fact that these streams were sampled only during February. The mean temperature in Four Mile Creek was 32.7°C, 13-16°C above the average temperature in most of the other creeks. The mean temperature in Beaver Dam Creek was 25.7°C, 7-9°C above the average temperature in most of the other creeks. The average oxygen concentration remained above 5.0 mg/L (the minimum level recommended by the EPA [1976] for a desirable fish community) in all streams, although lower concentrations were observed on isolated dates in nine streams.

A total of 1511 larvae and 539 eggs were collected from all creeks combined during 1985 (Table 3-4). The greatest numbers of ichthyoplankton were from Smith Lake Creek (716), followed by Buck Creek (314) and Steel Creek (250). Most of the fish eggs collected from SRP creeks during 1985 were from Steel Creek, Four Mile Creek, and Beaver Dam Creek. The eggs collected from Four Mile Creek and Beaver Dam Creek could not be definitely identified. Almost all of the eggs taken from Four Mile Creek were collected on May 7, when C-Reactor was down and temperatures were moderate (26.8°C; Figure 3-1), indicating that fish move into

Table 3-4. Ichthyoplankton abundance in Savannah River tributaries located between RM 89.3 and 187.1. February - July 1985.

Creek	(RM)	Mean discharge (m^3/sec)	No. dates sampled	Larvae	Eggs	Taxa	Mean density (no./1000 m^3)	Standard deviation (no./1000m^3)	Total ichthyo-plankton transported (millions)
Buck	(92.6)	0.0	23	314	0	8	129.7	220.4	0.0
Briar	(97.6)	15.1	26	82	12	10	21.0	41.7	2.2
The Gaul	(109.0)	0.0	3	1	0	1	11.5	28.1	0.0
Smith Lake	(126.5)	3.7	26	714	2	11	212.0	300.7	0.2
Lower Three Runs	(129.0)	1.2	23	67	8	7	28.4	36.8	0.5
Sweetwater	(133.5)	1.2	20	7	0	4	6.1	16.7	0.0
Steel	(141.6)	8.5	26	71	179	8	53.0	162.0	5.2
Four Mile	(150.6)	1.2	25	6	113	4	37.3	164.4	0.7
Beaver Dam	(152.1)	3.8	25	17	136	9	44.0	192.9	4.3
Upper Three Runs	(157.2)	2.8	25	73	18	8	41.3	62.5	1.0
Upper Boggy Gut	(162.2)	0.0	1	0	0	0	0.0	0.0	0.0
McBean	(164.2)	1.3	24	39	9	7	28.7	75.1	0.5
Hollow	(176.1)	2.4	26	111	32	6	48.3	70.5	2.1
Spirit	(183.3)	1.5	26	9	30	6	69.7	398.5	0.7
Total				1511	539				

NOTE: RIVIC18 and CRKPORT was used to compute the data presented in this table.

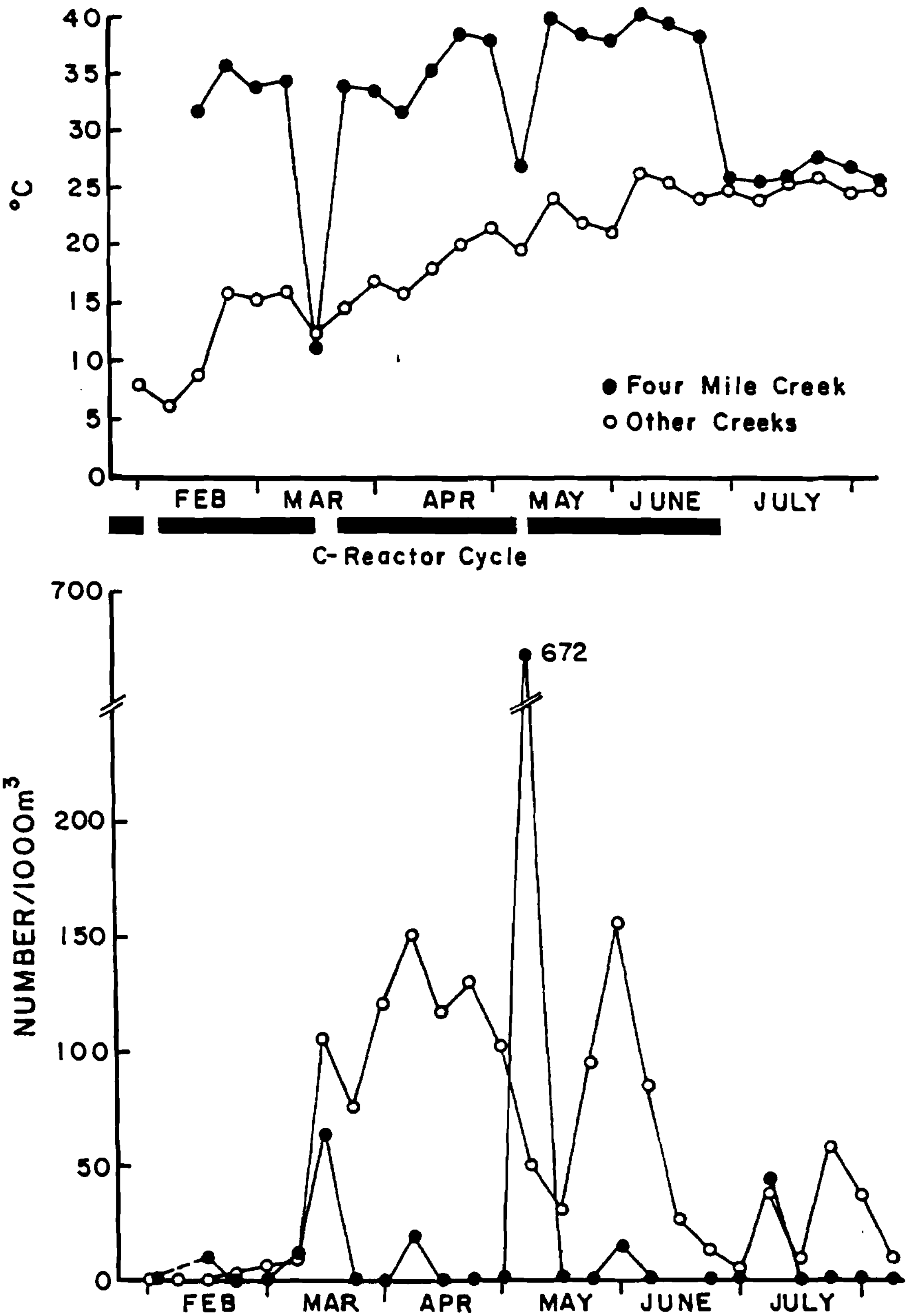


Figure 3-1. Mean ichthyoplankton density (no./1000 m^3) and temperature (°C) of Four Mile Creek and the nonthermal (all creeks except Steel Creek and Beaver Dam Creek) Savannah River tributary creeks (RIVIC13). February - July 1985.

this creek and spawn when temperatures are suitable. The eggs collected from Steel Creek were primarily those of American shad (44.1%) and blueback herring (35.8%, Table 3-5). Steel Creek also produced large numbers of blueback herring eggs in 1984 (61; Paller et al. 1985) and 1983 (95; Paller et al. 1984), indicating that it is a regular spawning area for this species.

Mean ichthyoplankton density in the creeks sampled during 1985 ranged from 0.0 organisms/1000 m^3 in Upper Boggy Gut to 212.0 organisms/1000 m^3 in Smith Lake Creek (Table 3-4). Steel Creek had the fourth-highest mean density (53.0/1000 m^3). This is less than the mean density recorded in Steel Creek in 1983 (123.0/1000 m^3) or 1984 (172.5/1000 m^3; Paller et al. 1984; 1985). The average density for all creeks sampled during 1985 was 52.2/1000 m^3. This was less than during 1983 (110.3/1000 m^3) and similar to 1984 (66.2/1000 m^3; both values adjusted to include only creeks upstream of RM 89.3). The differences observed could be related to differences in spawning success or creek discharge. Creek discharge averaged 21.3 m^3/sec in 1983, 10.5 m^3/sec in 1984 (values for creeks upstream of RM 89.3) and 3.1 m^3/sec in 1985. Reduced discharge could result in fewer larvae being carried from sheltered creek backwaters and swamps to the main creek channels where all sampling occurred.

Average monthly ichthyoplankton densities for 1985 were higher in the creeks than in the river during March and July (Figure 3-2). Mean densities during March and July were

Table 3-5. Percent abundance of eggs collected from Steel Creek, Four Mile Creek, and Beaver Dam Creek. February - July 1985.

Taxa	Steel Creek (RM 141.6)	Four Mile Creek (RM 150.6)	Beaver Dam Creek (RM 152.1)
blueback herring	35.8	1.8	22.8
American shad	44.1	0.0	1.5
yellow perch	2.8	0.0	0.7
other eggs	17.3	98.2	75.0
Total percent	100.0	100.0	100.0
Total number	179	113	136

NOTE: RIVIC11 was used to compute the data presented in this table.

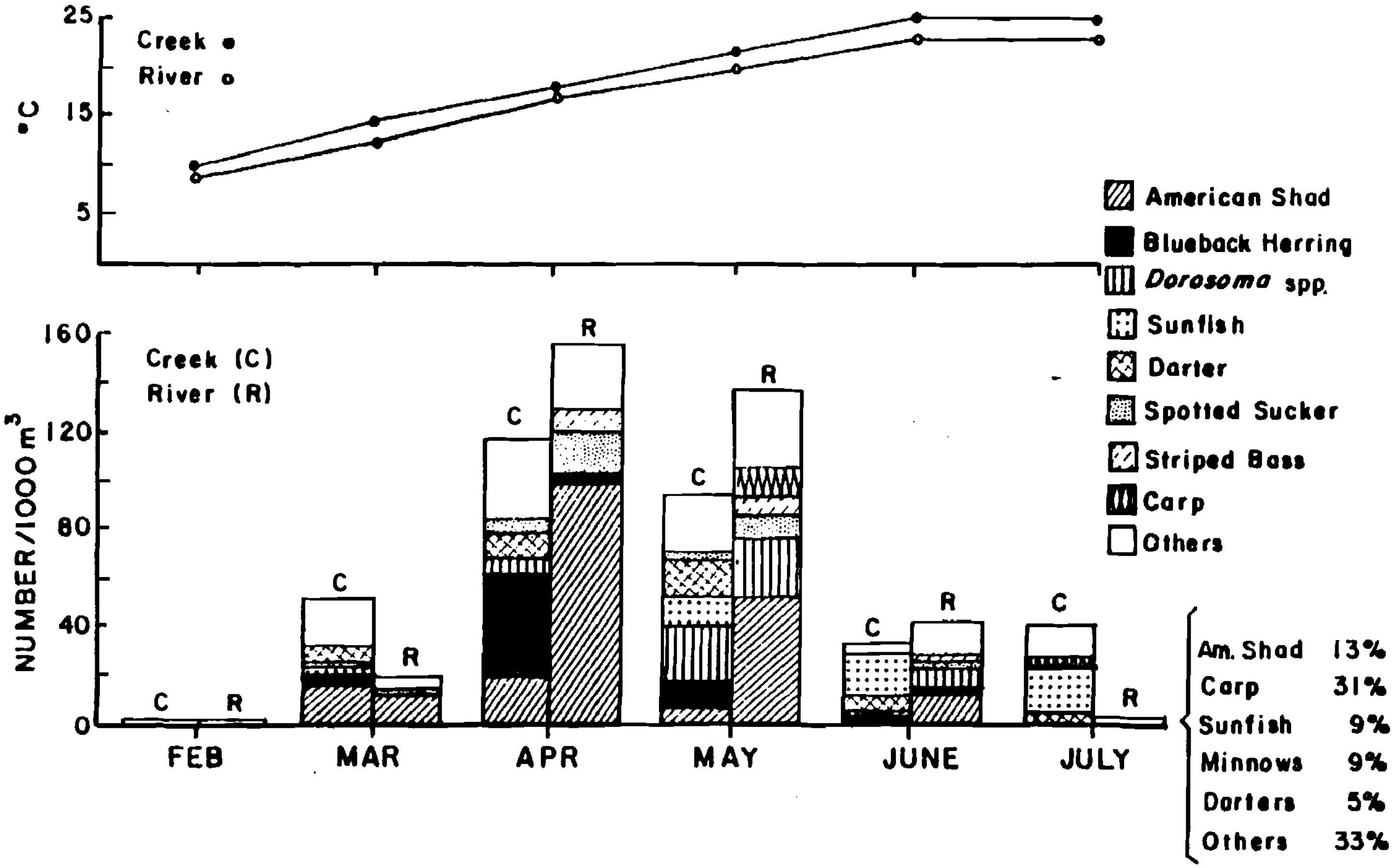


Figure 3-2. Average monthly ichthyoplankton density (no./1000 m^3) and taxonomic composition, and mean monthly temperatures (°C) for the Savannah River (R) and tributary creeks (C) (RIVIC10, RIVIC11, and RIVIC13). February - July 1985.

55.7/1000 m^3 and 42.8/1000 m^3, respectively, in the creeks and 18.3/1000 m^3 and 3.6/1000 m^3, respectively, in the river. The relatively high mean density in the creeks during March was due to an abundance of American shad, darters, blueback herring and other species, which may have spawned earlier in the creeks because of slightly higher temperatures (Figure 3-2). The relatively high mean density in the creeks during July was due primarily to sunfish spawning. Some sunfish species spawn throughout the summmer (Pflieger 1975). Except for March and July, river densities were higher than creek densities, due primarily to an abundance of American shad ichthyoplankton. While sometimes spawning in the lower reaches of tributary creeks, American shad often deposit their eggs in and near the main channel of large rivers (Jones et al. 1978; Leggett 1976). Taxa that used the creeks most during 1985 were blueback herring (19.3%), sunfish (13.2%), American shad (13.0%) and darters (12.1%). In contrast, American shad (50.7%) was the dominant taxon in the river (Figure 3-2; Table 3-6).

3.1.1.2 Ichthyoplankton Transport from Creeks into the Savannah River

The estimated total number of ichthyoplankton transported from creeks to the river during February - July 1985 ranged from approximately 0.0 in Buck Creek, The Gaul, Sweetwater, and Upper Boggy Gut to 5.2 million in Steel Creek (Table 3-4). The sampled creeks with the greatest transport during 1985 were Steel (5.2 million), Beaver Dam (4.3 million), Briar (2.2 million), and Hollow (2.1 million). While Beaver Dam Creek transported nearly

Table 3-6. Percent abundance and average density (no./1000 m^3) of fish larvae and eggs collected from the Savannah River, tributaries, oxbows, and the Savannah River Plant intake canals. February - July 1985.

	River[a]		Creeks[b]		Oxbows[c]		Intake Canals[d]	
Taxa	Percent Abundance	Density	Percent Abundance	Density	Percent Abundance	Density	Percent Abundance	Density
sturgeon	<0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
gar	0.0	0.0	0.0	0.0	0.0	0.0	0.2	<0.1
unid. Clupeidae	3.3	2.0	8.3	4.1	14.9	65.5	10.1	2.7
blueback herring	2.2	1.4	19.3	10.6	6.2	27.6	3.5	1.0
American shad	50.7	30.5	13.0	6.8	0.7	3.4	1.7	0.5
gizzard and/or threadfin shad	9.9	6.0	8.2	4.3	47.4	221.6	18.5	5.0
mudminnow	0.0	0.0	<0.1	<0.1	0.0	0.0	0.0	0.0
pickerel	<0.1	<0.1	0.2	0.1	0.0	0.0	0.2	<0.1
needlefish	<0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
minnow (Cyprinidae)	3.7	2.2	1.2	0.5	<0.1	0.1	3.1	0.8
carp	4.6	2.9	0.0	0.0	<0.1	0.2	9.1	2.3
unid. sucker	0.4	0.3	0.5	0.4	0.0	0.0	0.3	0.1
spotted sucker	8.1	4.9	2.8	5.3	<0.1	0.2	41.7	10.8
catfish and/or bullhead	<0.1	<0.1	<0.1	<0.1	0.0	0.0	0.0	0.0
swampfish	<0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
pirate perch	0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
topminnow	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.0	0.0
mosquitofish	<0.1	<0.1	0.0	0.0	<0.1	0.2	0.0	0.0
brook silverside	0.1	<0.1	5.1	2.5	0.2	0.6	0.4	0.1
striped bass	5.4	3.3	0.1	<0.1	0.1	0.2	5.6	0.9
unid. sunfish	0.3	0.2	1.8	0.9	1.8	8.8	0.3	0.1
sunfish (*Lepomis*)	0.7	0.4	11.4	5.8	18.9	87.7	0.2	<0.1
crappie	0.3	0.2	0.9	0.5	2.8	14.5	0.5	0.1
darter	0.7	0.4	12.1	6.9	2.5	11.5	3.0	0.8
yellow perch	0.2	0.1	0.8	0.4	3.6	18.4	0.0	0.0
unid. larvae	9.2	4.6	14.3	8.8	1.0	4.8	1.8	0.5
Totals	99.9	59.6	100.0	58.0	100.1	465.4	100.2	25.9
Number larvae and eggs collected	22,698		2050		10,322		605	

NOTE: RIVIC2, RIVIC10, and RIVICDE were used to compute the data presented in this table.

[a] Twenty-one transects between RM 89.3 and 187.1.
[b] Mouths of 14 tributary creeks.
[c] Five oxbows.
[d] 1G (RM 157.1) and 3G (RM 155.3) intake canals.

as much ichthyoplankton into the Savannah River as did Steel Creek, approximately 88% of the ichthyoplankton from Beaver Dam Creek consisted of nonbuoyant demersal eggs, possibly of blueback herring, minnows, suckers, and/or sunfish. The eggs of these species are not adapted for a pelagic existence and probably exhibit poor survival when scoured from their place of deposition. While the ichthyoplankton from Steel Creek also consisted largely of eggs (72%), approximately 44% of these eggs were those of American shad, a species whose eggs are well adapted for pelagic transport in river currents (Jones et al. 1978; Leggett 1976).

With the exception of Hollow Creek, all creeks with high transport numbers had greater than average discharges (Table 3-4). This factor, rather than high ichthyoplankton densities, was primarily responsible for the high transport numbers. Conversely, certain creeks, such as Buck Creek, had high densities but low transport numbers because of their low discharge.

One method of evaluating the contribution of each creek to the river is to compare its ichthyoplankton transport with the number of ichthyoplankton transported in the river. Cumulative transport from Steel Creek (RM 141.6) was 5.2 million, compared with 212.8 million at the river transect just above Steel Creek (RM 141.7; Table 3-7). Thus, the ichthyoplankton transported from Steel Creek increased river ichthyoplankton levels by approximate-

Table 3-7. Cumulative number of ichthyoplankton transported past transects in the Savannah River and from the mouths of selected Savannah River tributaries during the period from February - July 1985.

Location (River Mile)	Cumulative transport (millions)
River transect[a]	
97.5	121.8
110.0	154.8
120.0	141.2
128.9	167.4
129.1	143.5
137.7	145.9
141.5	129.9
141.7	212.8
145.7	224.2
150.4	115.6
150.8	80.5
152.0	76.0
152.2	93.0
155.2	144.4
155.4	132.6
157.0	119.4
157.3	210.7
166.6	370.1
176.0	169.9
187.1	141.1
Creek transect	
Buck Creek (92.6)	0.0
Briar Creek (97.6)	2.2
The Gaul (109.0)	0.0
Smith Lake Creek (126.5)	0.2
Lower Three Runs Creek (129.0)	0.5
Sweetwater Creek (133.5)	0.0
Steel Creek (141.6)	5.2
Four Mile Creek (150.6)	0.7
Beaver Dam Creek (152.1)	4.3
Upper Three Runs Creek (157.2)	1.0
Upper Boggy Gut Creek (162.2)	0.0
McBean Creek (164.2)	0.5
Hollow Creek (176.1)	2.1
Spirit Creek (183.3)	0.7

NOTE: RIVTRA3 and CRKPORT were used to compute the data presented in this table.

[a]Transport at the river transects is based on discharge data taken at RM 119.7, RM 156.8, and RM 187.4. Discharge was calculated individually for each creek.

ly 2%. Most other creeks made smaller contributions than Steel Creek, indicating that all creeks made minimal contributions to the river ichthyoplankton assemblage during 1985. During 1984, in contrast, ichthyoplankton transported from large creeks such as Briar, increased river ichthyoplankton levels by as much as approximately 70% (Paller et al. 1985). Steel Creek transport raised river ichthyoplankton levels by an estimated 13% during 1984. In general, creek-to-river transport during 1985 was very low in comparison with previous years. Mean transport from the creeks sampled during all three years (i.e., those above RM 89.3) was 53.4 million during 1983, 17.8 million during 1984, and 1.2 million during 1985. Steel Creek transport dropped from 77.2 million during 1983 (Paller et al. 1984) to 53 million during 1984 (Paller et al. 1985) to 5.2 million during 1985. Mean discharges from these creeks were 21.3 m^3/s in 1983, 10.5 m^3/s in 1984, and 3.1 m^3/s in 1985 (Table 3-8).

Reduced creek-to-river transport during 1985 was a function of decreased discharge and possibly of decreased spawning (Table 3-8). Decreased discharge would tend to result in larvae remaining in the creeks rather than being passively transported into the river. In addition, the relatively low larval densities observed in the creeks during 1985 may be an indication of decreased spawning. Water levels were low during the 1985 spawning season. Many species spawn most successfully when flood waters inundate terrestrial areas, thus producing more spawning habitat (i.e., flooded terrestrial vegetation) and providing more

Table 3-8. Mean February - July discharge (m^3/s) and density (no./1000 m^3) in Savannah River tributaries sampled during 1983, 1984, and 1985.

	1983		1984		1985	
Creeks (RM)	Dis	Den	Dis	Den	Dis	Den
Buck (92.6)	28.1	383	3.3	69	0.0	130
Briar (97.6)	86.4	140	62.4	158	15.1	21
The Gaul (109.0)	6.7	75	2.2	83	0.0	12
Smith Lake (126.5)	48.5	90	24.3	51	3.7	212
Lower Three Runs (129.0)	2.7	187	1.0	14	1.2	28
Sweetwater (133.5)	33.4	51	9.1	18	1.2	6
Steel (141.6)	26.2	123	16.3	173	8.5	53
Four Mile (150.6)	4.1	50	3.0	46	1.2	37
Beaver Dam (152.1)	8.3	74	2.1	40	3.8	44
Upper Three Runs (157.2)	15.8	25	9.2	25	2.8	41
Upper Boggy Gut (162.2)	9.5	43	5.8	5	0.0	0
McBean (164.2)	5.1	93	2.1	23	1.3	29
Hollow (176.1)	14.5	53	2.7	45	2.4	48
Spirit (183.3)	8.6	157	2.8	113	1.5	70
Mean	21.3	110	10.5	62	3.1	52

shelter and greater food supplies (i.e., zooplankton blooms) for larval fish (Martin et al. 1981; Krykhtin 1975).

While creek-to-river transport was highly variable between years, Steel Creek consistently demonstrated high transport in relation to the other creeks in the upper half of the study area. Steel Creek was the fourth most productive creek (in terms of transport number) above RM 89.3 in 1983, the second most productive in 1984, and the most productive in 1985. Relatively high ichthyoplankton transport from Steel Creek during three years with dissimilar river hydrologic patterns strengthens the contention that this creek is an important spawning area.

Calculation of the transport of ichthyoplankton from the creeks to the river can provide a useful indication of the contribution of various creeks to total river ichthyoplankton. However, the significance of the calculated transport values of ichthyoplankton from any creek should be interpreted cautiously for several reasons. First, because of the variability in ichthyoplankton densities and the difficulties in determining river and creek discharges, transport numbers should be regarded as approximations only. Second, the most important function of the creeks for resident fish populations may be to serve as nursery areas rather than as spawning areas. As nursery areas, the creeks may provide habitat where larval fishes can grow to less vulnerable sizes before entering the river. Last, it is difficult to evaluate the significance of a localized 8 - 10% increase or decrease in ichthyoplankton on a river fish community because biological communities are able to compensate for population losses and because density-dependent mortality increases with abundance (Odum 1971; Goodyear 1980).

3.1.1.3 Ichthyoplankton Abundance in Selected SRP Creeks

The major SRP streams that discharge directly into the Savannah River are Lower Three Runs Creek (RM 129.0), Steel Creek (RM 141.6), Four Mile Creek (RM 150.6), Beaver Dam Creek (RM 152.1), and Upper Three Runs Creek (RM 157.2; Figure 3-3). Steel Creek received thermal effluent for 14 years until discharge ceased 18 years ago. During the four years of this study, it has been recovering from the impact of the heated discharge. The upper reach of Steel Creek carries natural runoff and ambient temperature process effluents from P-Reactor. Under normal water conditions, the lower reach of the creek drains a large portion of the SRP river floodplain swamp. Pen Branch carries thermal discharge from K-Reactor and joins Steel Creek upstream from the sample station after flowing through approximately 7 km of swamp. By the time Pen Branch water reaches the Steel Creek swamp, it has cooled considerably, although the water temperature can still be slightly above ambient under flood conditions (Shines and Tinney 1983). Therefore, water at the Steel Creek confluence with the Savannah River, where the ichthyoplankton samples were collected, is a combination of natural drainage from Steel Creek, process effluents

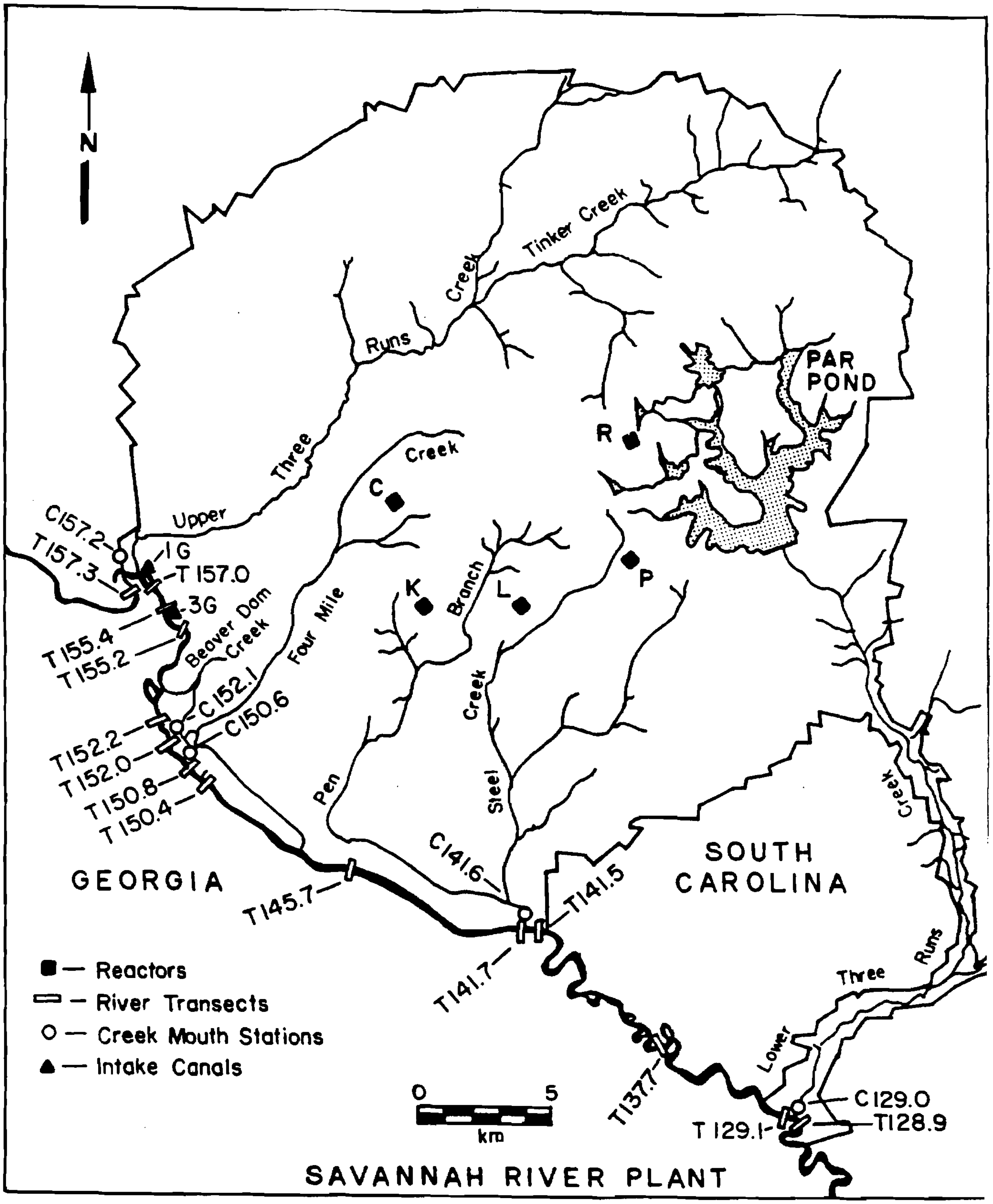


Figure 3-3. Map of the Savannah River Plant showing the location of Savannah River tributary creeks.

from P-Reactor, and ambient or near-ambient temperature reactor cooling water from Pen Branch.

Four Mile Creek and Beaver Dam Creek receive heated effluents from C-Reactor and the coal-fired power station in D-Area, respectively (Figure 3-3). Four Mile Creek is the hotter of the two streams (Table 3-2; Ashley et al. 1984). Both creeks receive some natural swamp drainage in their lower reaches before discharging into the Savannah River. In addition, some discharge from Four Mile Creek flows into the lower reaches of Beaver Dam Creek when water levels are low. During river flooding, both creeks can flow through the onsite swamp and enter the SR south of Steel Creek.

Lower Three Runs Creek and Upper Three Runs Creek are located at the southeast and northwest boundaries of the SRP, respectively (Figure 3-3). Upper Three Runs Creek is the only major SRP stream that is not thermally impacted. Lower Three Runs does not receive thermal effluent directly, but receives overflow from Par Pond, a cooling reservoir for P-Reactor.

The impacts of cooling water effluents on fish spawning habitats in the creeks on the SRP was an important consideration of this study. Of particular concern were potential impacts on spawning areas in Steel Creek that would result from the re-start of L-Reactor. This report section presents an evaluation of the importance of the major creeks on the SRP as spawning areas within the Savannah River drainage by comparing their ichthyoplankton density, taxonomic composition, time of ichthyoplankton appearance, and number of ichthyoplankton transported into the river to other Savannah River tributaries. While these were important measures of the value of each creek as a spawning area, they did not take into account larval mortality or the importance of each creek as a nursery area for juvenile fish.

Steel Creek - Ichthyoplankton (primarily darters) were first collected from Steel Creek in early February (Figure 3-4). Densities increased steadily throughout February and March, rising to a peak of 587.5 organisms/1000 m^3 in early April. This peak strongly influenced mean density and total transport values in Steel Creek (Table 3-4). Densities subsequently fell to approximately 37.7/1000 m^3 in late April, peaked again briefly in May, then declined during the rest of the study period. By late July, densities had dropped below 10/1000 m^3, indicating that most of the spawning in Steel Creek during 1985 was over.

The taxonomic composition of the ichthyoplankton from Steel Creek differed somewhat from the ichthyoplankton composition of the other creeks. Steel Creek had the highest percentage of blueback herring (27.2%) and American shad (33.2%) of any creek sampled during 1985 (Tables 3-9, 3-10, and 3-11). The only other creek with nearly comparable percentages of these species was Buck Creek (26.1% blueback herring and 30.3% American shad). Beaver Dam Creek had a fairly high percentage of blueback herring (20.3%) but few American shad (1.3%), as did Spirit Creek (25.6% blueback

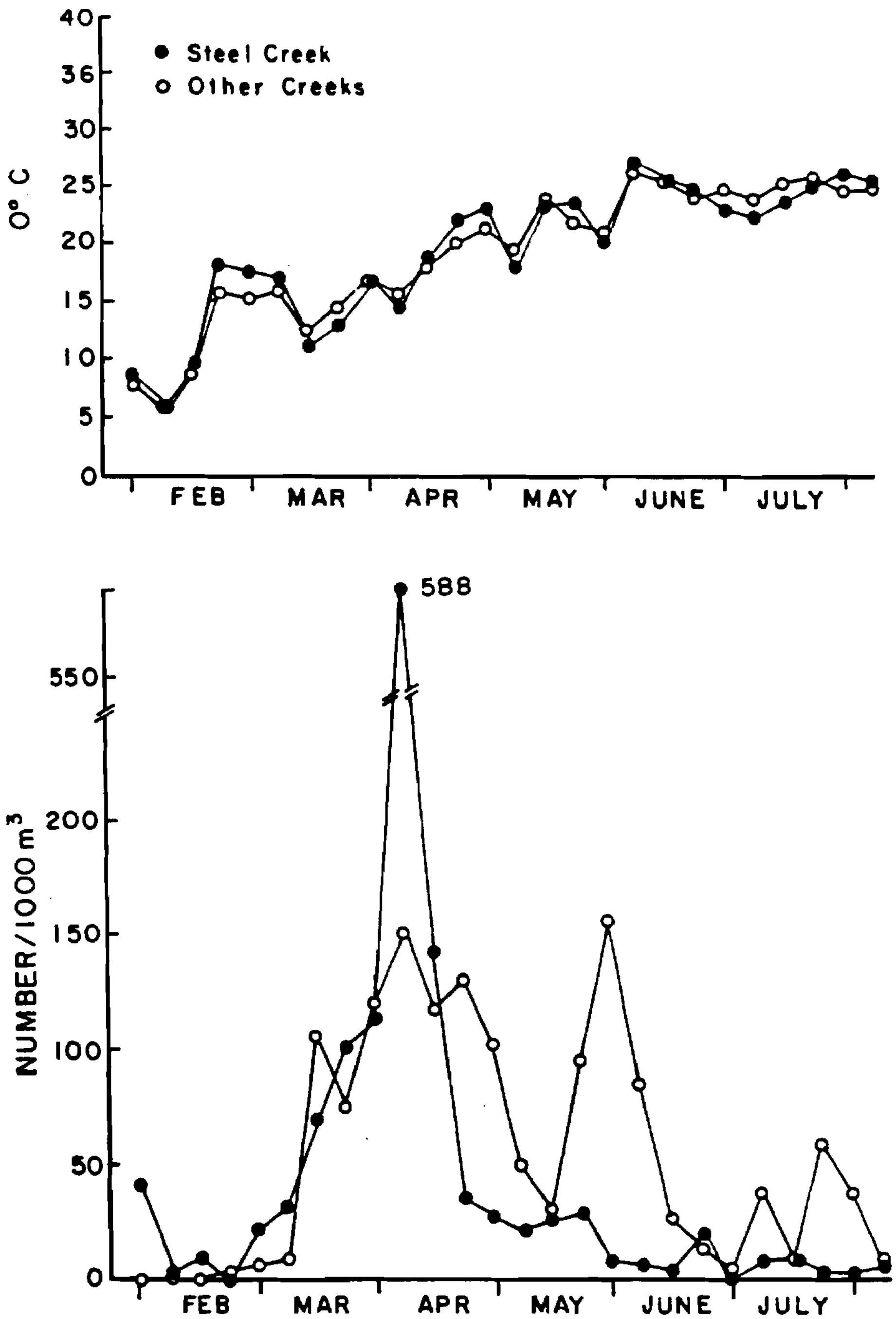


Figure 3-4. Mean ichthyoplankton density (no./1000 m^3) and temperature (°C) of Steek Creek and other nonthermal (all creeks except Four Mile Creek and Beaver Dam Creek) Savannah River tributary creeks (RIVIC13). February - July 1985.

Table 3-9. Percent composition of ichthyoplankton in the nearfield creeks of the Savannah River (RM). February - July 1985.

Taxa	Lower Three Runs Creek (129.0)	Sweet-water Creek (133.5)	Steel Creek (141.6)	Four Mile Creek (150.6)	Beaver Dam Creek (152.1)	Upper Three Runs Creek (157.2)
gar	-	-	-	-	-	-
unid. Clupeidae	1.3	-	1.6	-	-	-
blueback herring[a]	8.0	-	27.2	1.7	20.3	12.1
American shad[a]	-	-	33.2	-	1.3	6.6
gizzard and/or threadfin shad[a]	-	-	-	-	-	2.2
pickerel	-	-	-	-	0.7	-
minnow (Cyprinidae)[a]	1.3	-	4.0	-	2.6	1.1
carp	-	-	-	-	-	-
unid. sucker	6.7	-	0.4	-	-	5.5
spotted sucker	1.3	14.3	1.2	-	-	44.0
catfish and/or bullhead	-	-	-	-	0.7	-
pirate perch	-	-	-	-	-	-
topminnow	-	-	-	-	0.7	-
brook silverside	-	-	0.4	0.8	-	-
striped bass[a]	-	-	-	-	-	-
unid. sunfish	20.0	14.3	3.6	-	0.7	2.2
sunfish (<u>Lepomis</u>)	-	14.3	1.2	1.7	1.3	-
crappie	6.7	-	-	0.8	-	1.1
darter	41.3	28.6	12.0	-	2.0	14.3
yellow perch[a]	4.0	28.6	2.0	-	2.6	-
unid. larvae	4.0	-	0.8	1.7	0.7	-
other eggs	5.3	-	12.4	93.3	66.7	11.0
Total percent	99.9	100.1	100.0	100.0	100.3	100.1
Total larvae and eggs	75	7	250	119	153	91
Number of sample dates	23	20	26	25	25	25

NOTE: RIVIC10 was used to compute the data presented in this table.

[a]These categories include larvae and eggs. Other categories include only larvae.

Table 3-10. Percent abundance of ichthyoplankton in the lower farfield creeks of the Savannah River (RM). February - July 1985.

Taxa	Buck Creek (92.6)	Briar Creek (97.6)	The Gaul (109.0)	Smith Lake Creek (126.5)
gar	-	-	-	-
unid. Clupeidae	12.4	11.7	-	16.1
blueback herring[a]	26.1	10.6	-	19.8
American shad[a]	30.3	3.2	-	8.7
gizzard and/or threadfin shad[a]	2.2	2.1	-	18.7
mudminnow	-	-	-	0.1
pickerel	-	1.1	-	0.3
minnow (Cyprinidae)[a]	0.3	4.3	-	-
carp	-	-	-	-
unid. sucker	-	-	-	-
spotted sucker	-	4.3	-	0.1
catfish and/or bullhead	-	-	-	-
pirate perch	-	-	-	-
topminnow	-	-	-	-
brook silverside	1.9	1.1	-	12.4
striped bass[a]	-	2.1	-	-
unid. sunfish	0.3	5.3	-	0.3
unid. sunfish (Lepomis)	23.2	2.1	-	20.7
largemouth bass	-	-	-	-
crappie	-	-	-	1.5
darter	1.3	41.5	-	0.6
yellow perch[a]	0.3	-	-	0.1
unid. larvae	1.6	1.1	100.0	0.5
other eggs	-	9.6	-	-
Total percent	99.9	100.1	100.0	99.9
Total larvae and eggs	314	94	1	716
Number of sample dates	23	26	3	26

NOTE: RIVIC10 was used to compute the data presented in this table.

[a]These categories include larvae and eggs. Other categories include only larvae.

Table 3-11. Percent abundance of ichthyoplankton in the upper farfield creeks of the Savannah River (RM). February - July 1985.

Taxa	McBean (164.2)	Hollow (176.1)	Spirit (183.3)
gar	-	-	-
unid. Clupeidae	-	-	-
blueback herring[a]	20.8	16.8	25.6
American shad[a]	16.7	4.9	-
gizzard and/or threadfin shad[a]	2.1	2.8	46.2
mudminnow	-	-	-
pickerel	-	-	-
minnow (Cyprinidae)[a]	4.2	-	2.6
carp	-	-	-
unid. sucker	-	-	-
spotted sucker	-	2.1	10.3
catfish and/or bullhead	-	-	-
pirate perch	-	-	-
topminnow	-	-	-
brook silverside	4.2	-	7.7
striped bass[a]	-	-	-
unid. sunfish	-	-	-
sunfish (Lepomis)	4.2	-	-
crappie	-	-	-
darter	45.8	69.2	2.6
yellow perch[a]	-	1.4	-
unid. larvae	2.1	2.1	-
other eggs	-	0.7	5.1
Total percent	100.1	100.0	100.1
Total larvae and eggs	48	143	39
Number of sample dates	24	26	26

NOTE: RIVIC10 was used to compute the data presented in this table.

[a]These categories include larvae and eggs. Other categories include only larvae.

herring, 0.0% American shad). The collection of large numbers of blueback herring from Steel Creek during 1985 is consistent with the findings from 1983 and 1984. More blueback herring were collected from Steel Creek than from any other creek in the nearfield or upper farfield (Paller et al. 1984, 1985). American shad, however, were collected in much greater numbers during 1985 (83) than during 1983 (20) or 1984 (19).

Four Mile Creek - Ichthyoplankton were first collected from Four Mile Creek in mid-February (Figure 3-1). However, densities were low (under 10 ichthyoplankton/1000 m^3) until March 19, when densities briefly peaked at 63.2/1000 m^3. This peak was associated with a temporary drop in temperature to approximately 11°C, due to a brief C-Reactor shut down. When C-Reactor began operating again, temperatures rapidly climbed to approximately 33°C, and ichthyoplankton densities declined to zero. Another stronger ichthyoplankton density peak (672/1000 m^3) was observed in early May, again associated with a brief C-Reactor shutdown. The last major density peak in Four Mile Creek occurred in early July when C-Reactor shut down again (and remained down for the rest of the study period). These data suggest that ichthyoplankton are largely absent from the mouth of Four Mile Creek when the reactor is operating and water temperatures are high, but that fish will rapidly move into Four Mile Creek and begin spawning as soon as the reactor shuts down. This general pattern of low or zero densities punctuated by a few brief peaks was also observed in Four Mile Creek during 1984 (Paller et al. 1985).

Most of the ichthyoplankton collected from the mouth of Four Mile Creek were unidentified eggs (93.3%, Table 3-9). The majority of these eggs were collected during the density peak on May 7. Other taxa found in Four Mile Creek were blueback herring (1.7%), brook silverside (0.8%), unidentified sunfish (1.7%), and crappie (0.8%). The predominance of "other" fish eggs in the Four Mile Creek collection may be due to the relatively high current velocities in this stream (42.5 cm/s on May 7, when most of the eggs were collected) and to the lack of submerged vegetation, leaf accumulations, or other substrates that many fishes use to attach or shelter eggs (Breder and Rosen 1966). These materials are generally scoured out of Four Mile Creek by C-Reactor discharge.

Beaver Dam Creek - Ichthyoplankton were first collected from Beaver Dam Creek during early February (19.3/1000 m^3; Figure 3-5). Densities progressively increased during March, reaching a peak of 692/1000 m^3 in early April. This peak strongly influenced the mean density and total transport values in Beaver Dam Creek (Table 3-4). Ichthyoplankton densities subsequently declined, reaching very low levels (4/1000 m^3) by late April. During May, June, and July, densities were either very low (under 13/1000 m^3) or zero. The predominant taxa in Beaver Dam Creek were blueback herring (20.3%) and unidentified eggs (66.7%; Table 3-9). As in Four Mile Creek, the predominance of unidentified eggs was probably due to

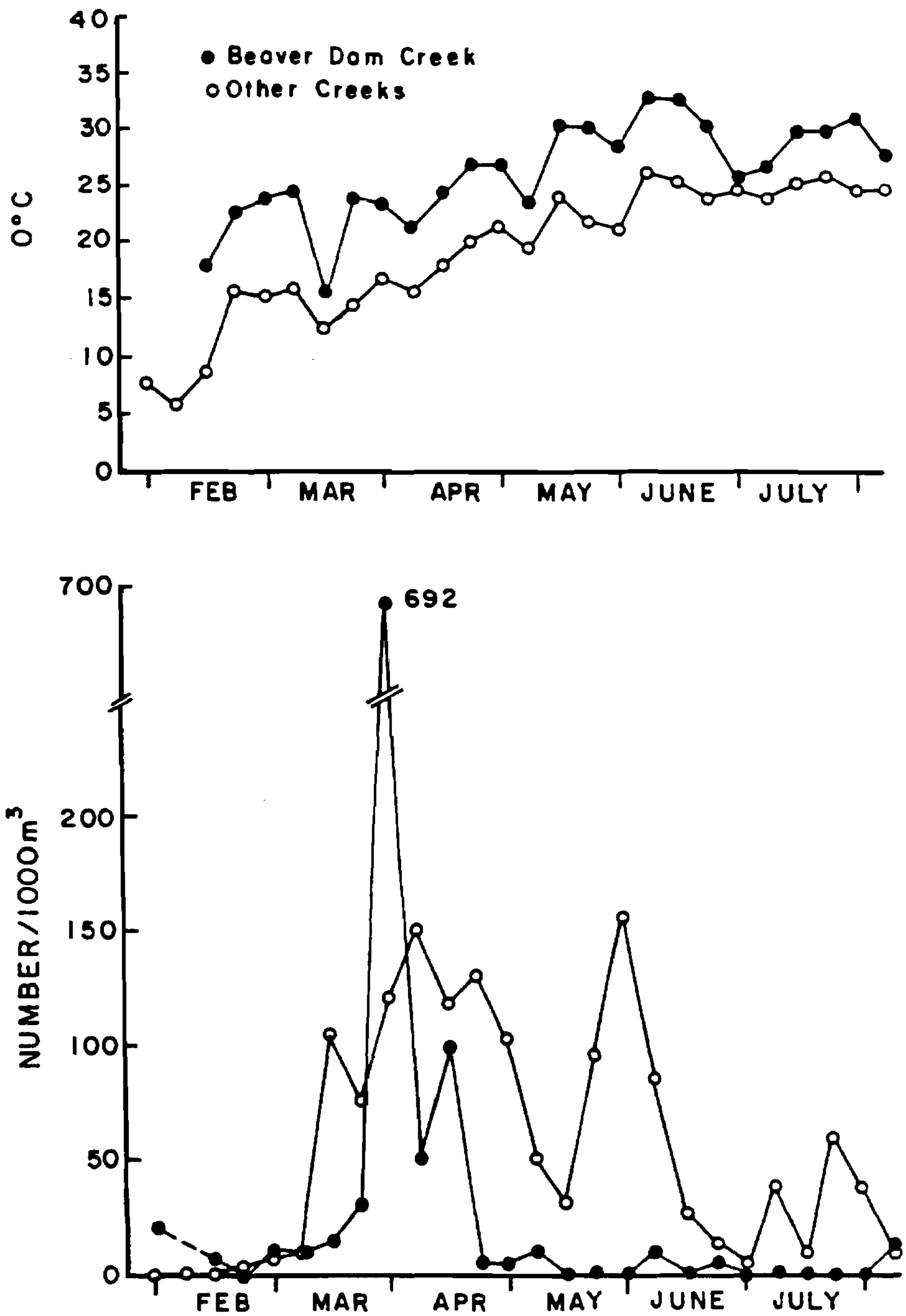


Figure 3-5. Mean ichthyoplankton density (no./1000 m^3) and temperature (°C) of Beaver Dam Creek and the nonthermal (all creeks except Four Mile Creek and Steel Creek) Savannah River tributary creeks (RIVIC13). February - July 1985.

strong currents (mean of 77.5 cm/s on April 2, when most of the eggs were collected) that dislodged eggs from spawning areas.

Temperatures in Beaver Dam Creek were approximately 1 - 8°C above the average temperatures of the other creeks. There were indications that spawning may have been reduced in Beaver Dam Creek during May, June, and July, when temperatures were highest (up to 33°C). Average density in Beaver Dam Creek was approximately 3.6 organisms/1000 m^3 during June and July in contrast to 40.1/1000 m^3 in the other creeks during these months. Reduced spawning in Beaver Dam Creek in relation to the other creeks was also observed during June and July 1984 (Paller et al. 1985).

3.1.2 River Ichthyoplankton

3.1.2.1 Chemical and Physical Parameters in the River

Water chemistry measurements in the Savannah River (including intake canals) indicated that the river water was generally well oxygenated. Average oxygen concentrations over the entire February - July sample period varied from 6.6 mg/L at RM 110.0 and RM 120.0 to 8.8 mg/L at RM 187.1 (Table 3-12). The water was slightly acidic (mean pH of 6.5 over all transects). Alkalinities averaged 18.3 mg $CaCO_3$ over all transects.

The average temperature over the entire February - July study period varied from 15.9°C at RM 187.1 to 19.0°C at RMs 97.5 and 89.3. Temperatures demonstrated a progressive decrease from the

Table 3-12. Chemical and physical parameters [mean (range)] at each Savannah River transect. February - July 1985.

River Mile	Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity (μS/cm)	pH	Alkalinity (mg/L)	Number of dates sampled
89.3	19.0 (6.3-26.5)	6.9 (4.9- 9.2)	88.1 (60.0-124.0)	6.6 (4.7- 8.4)	18.8 (10.9-22.0)	26
97.5	19.0 (5.6-26.5)	6.8 (5.1- 9.5)	87.3 (56.0-126.0)	6.5 (4.0- 8.4)	18.9 (7.0-38.0)	26
110.0	18.9 (6.5-25.5)	6.6 (4.4- 8.3)	82.2 (38.0-110.0)	6.5 (4.3- 8.2)	18.2 (11.5-22.0)	26
120.0	18.5 (6.0-26.0)	6.6 (4.4- 8.4)	83.1 (38.0-114.0)	6.5 (4.7- 7.9)	19.4 (13.3-34.9)	26
128.9	18.4 (7.0-25.3)	6.8 (4.8-12.3)	85.4 (46.0-121.0)	6.3 (4.1- 7.9)	18.1 (11.0-21.0)	26
129.1	18.3 (7.0-25.2)	6.8 (4.8-12.3)	85.4 (46.0-121.0)	6.3 (4.2- 7.8)	18.1 (11.0-21.0)	26
137.7	18.0 (7.0-24.7)	6.7 (4.4-11.4)	84.6 (44.0-118.0)	6.2 (4.5- 7.8)	18.2 (11.0-21.8)	26
141.5	17.8 (6.0-24.9)	6.8 (4.4-11.5)	83.4 (43.0-118.0)	6.3 (4.3- 9.1)	18.2 (11.0-21.3)	26
141.7	18.8 (7.0-25.1)	6.8 (4.8-11.3)	84.4 (43.0-128.0)	6.4 (4.3- 7.3)	18.0 (11.0-21.5)	26
145.7	18.0 (7.5-24.4)	6.9 (4.8- 9.1)	84.3 (68.0- 95.0)	6.7 (5.4- 7.9)	18.3 (11.3-21.5)	25
150.4	18.5 (6.9-26.0)	6.9 (5.3- 9.2)	86.8 (70.0-101.0)	6.6 (5.5- 7.9)	18.0 (13.8-27.5)	26
150.8	18.2 (6.8-24.6)	7.0 (5.4- 9.3)	87.3 (68.0-100.0)	6.6 (5.6- 8.0)	18.1 (10.0-21.5)	26
152.0	18.1 (6.6-25.1)	7.0 (4.7- 9.4)	87.8 (69.0-100.0)	6.5 (5.5- 8.1)	18.3 (10.0-22.0)	26
152.2	17.8 (7.4-24.5)	7.1 (5.1- 9.3)	87.2 (70.0-100.0)	6.5 (5.2- 8.2)	18.6 (11.5-22.3)	26
155.2	17.4 (6.6-24.0)	7.4 (4.8-10.2)	84.4 (50.0-100.0)	6.6 (5.3- 8.0)	18.6 (11.8-21.3)	26
155.3[a]	17.6 (7.0-26.1)	7.0 (4.7-10.2)	81.5 (36.0- 98.0)	6.6 (5.3- 7.8)	18.7 (11.3-27.5)	26
155.4	17.3 (7.0-23.8)	7.3 (4.8-10.1)	83.7 (49.0-100.0)	6.5 (4.7- 8.4)	18.2 (11.3-25.0)	26
157.0	17.1 (7.0-23.5)	7.3 (4.6-10.2)	83.6 (42.0-109.0)	6.5 (5.4- 7.7)	18.7 (9.0-27.0)	26
157.1[a]	17.6 (7.0-26.4)	7.0 (4.3- 9.5)	69.8 (28.0- 86.0)	6.6 (5.2- 7.8)	15.4 (7.3-20.5)	26
157.3	17.0 (7.1-23.5)	7.3 (4.7- 9.8)	84.8 (45.0-102.0)	6.6 (5.4- 7.7)	19.2 (11.5-22.0)	26
166.6	16.6 (6.7-22.5)	7.5 (5.2-10.2)	83.3 (50.0-108.0)	6.5 (4.6- 8.4)	18.7 (12.5-22.0)	26
176.0	16.6 (6.8-23.7)	8.2 (5.3-13.6)	81.3 (51.0-110.0)	6.5 (4.5- 8.3)	19.3 (13.3-34.0)	26
187.1	15.9 (6.8-23.0)	8.8 (5.5-11.6)	58.2 (39.0- 88.0)	6.5 (4.5- 7.6)	15.8 (13.3-20.4)	26

[a]Intake canals.

downstream to the upstream end of the study area, indicating the presence of a temperature gradient in the Savannah River. The gradient is probably due to a combination of cool hypolimnetic discharge from Clarks Hill Reservoir at RM 221.7 and gradual warming due to solar insolation as the water moves downstream. Similar temperature gradients were observed during 1983 and 1984 (Paller et al. 1983, 1984).

Examination of average temperatures at transects near the SRP indicates that the average temperature at RM 150.4 (downstream from FMC mouth) was slightly higher (0.3 - 0.5°C) than at the transects immediately preceding and following it (Table 3-12). This difference is probably due to the discharge of heated water from Four Mile Creek into the river at RM 150.6. Temperatures in the mouth of Four Mile Creek over the entire study period averaged 32.7°C, and flow from the creek to the river was relatively strong (Tables 3-2 and 3-3). Since Four Mile Creek discharges on the South Carolina side of the Savannah River, temperatures would be expected to be highest near the South Carolina bank. Mean temperatures were calculated for each transect during each month of the study, using South Carolina bank data only (Figure 3-6). Temperature increases along the South Carolina bank were prominent at RM 150.4, reaching several degrees above ambient river temperatures during April.

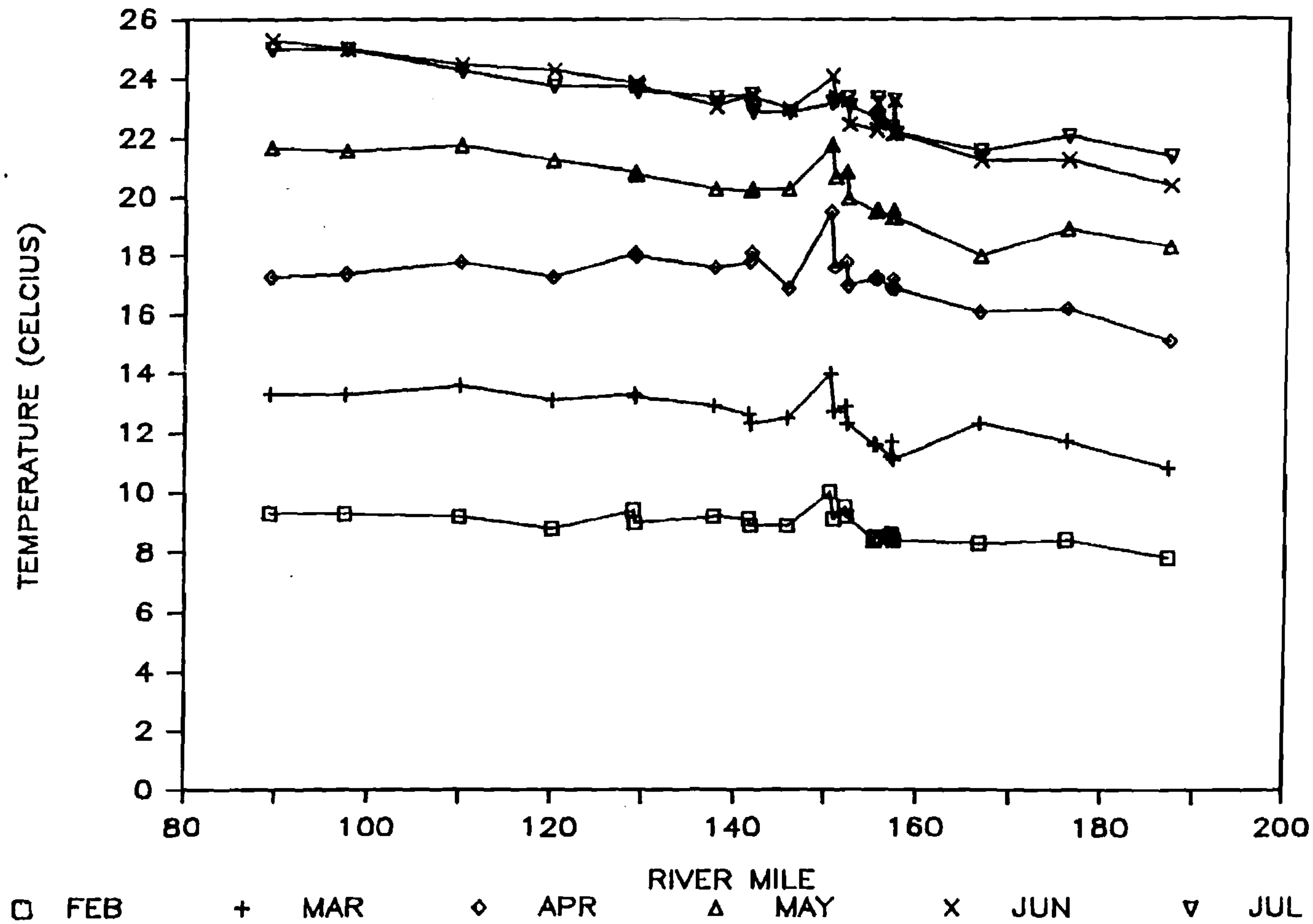


Figure 3-6. Mean monthly temperatures for the South Carolina side of the Savannah River transects. February - July 1985.

3.1.2.2 Analysis of Variance for River Ichthyoplankton Density

The distribution of ichthyoplankton in rivers tends to be spatially and temporally heterogeneous, varying from bank to bank, top to bottom, transect to transect, and date to date (Marcy 1976; Lathrop 1982; and Hergenrader et al. 1982). To provide a general overview of the relative importance of these sources of variability, analysis of variance (GLM procedure; SAS 1982) was conducted on total ichthyoplankton density (all taxa) using net (i.e., the paired nets were separated into net A and net B), bank, depth (i.e., top or bottom), transect, sample date, and various two-factor interaction terms as the classification variables. (Higher-level interaction could not be tested because of limited computer space.) In other sections of this report, less general testing procedures are used to resolve specific questions concerning ichthyoplankton distribution.

Analysis of variance indicated that differences between the independent variables accounted for 83% of the variability of the nearfield ichthyoplankton data (Appendix 3 Table 1). Most of the variability was associated with density differences between sampling dates. An F test indicated that sampling date was statistically significant at $p \leq 0.0001$. While no other variable accounted for nearly as much variability in ichthyoplankton density, many were statistically significant at $p \leq 0.05$. Significant variables other than date were depth, transect, bank, net/depth interaction, bank/transect interaction, transect/sampling date interaction, bank/sampling date interaction, bank/depth interaction, and depth/ sampling date interaction.

For the upper farfield, the GLM procedure indicated that differences between independent variables accounted for 89% of the observed variability in ichthyoplankton density (Appendix 3 Table 2). Sampling date accounted for most of this. Other statistically significant factors ($p \leq 0.05$) were bank, depth, transect, bank/depth interaction, bank/sampling date interaction, depth/sampling date interaction, and transect/sampling date interaction.

In the lower farfield, independent variables accounted for 83% of the observed differences in ichthyoplankton density (Appendix 3; Table 3). Again, sampling date was the most important variable. Other significant ($p \leq 0.05$) variables were net, bank, depth, transect, bank/transect interaction, transect/sampling date interaction, depth/sampling date interaction, and net/depth interaction. The occurrence of a significant net/depth interaction suggests that the relative performance of the individual nets in the paired-net configuration differed somewhat with depth. However, since the variance associated with this factor was less than 0.1% of the total variance, any bias associated with this potential performance difference is of little practical importance.

Most of the variability in ichthyoplankton density observed in the study was associated with sampling date (Appendix 3, Tables 1 - 3). This was expected because of the influence that seasonal changes in photoperiod, temperature, water level, and other factors have on spawning activity (Nikolsky 1963). The next most important factor was the transect/sampling date interaction, indicating that a significant portion of the total variability was associated with temporal changes among transects. Other factors of less importance were horizontal (bank) and vertical (depth) position in the water column and transect location. The same pattern was observed in the 1984 data, with most of the variance attributable to sampling date, followed by the transect/sampling date interaction. In the following discussion, differences observed between transects, banks and depths will be scrutinized in greater detail.

3.1.2.3 Vertical Distribution of Ichthyoplankton

Ichthyoplankton densities in near-surface and near-bottom samples were compared at each transect over all sampling dates to identify vertical distribution patterns. This series of tests was done, to identify transects where consistent long-term vertical density differences occurred. Top/bottom comparisons were also done with the sampling dates divided into monthly intervals to identify locations where short-term vertical density differences occurred. Because larvae may actively avoid the bottom and because larvae and eggs differ in shape (which may affect their rate of settling), their two life stages were analyzed separately.

Analysis of larval densities over all dates (t-test) showed an absence of significant ($p \leq 0.05$) differences between top and bottom samples at all transects except RM 120.0 (Table 3-13). Tests of top/bottom differences at each transect during each month indicated generally similar results, with only a few significant findings. To conserve space, the results of these tests will not be presented. The generally uniform vertical distribution of the fish larvae was probably due to the mixing action of the river. These finding corroborate the results of the 1982, 1983, and 1984 sampling programs (ECS 1983; Paller et al. 1984, 1985), which indicated that larvae were uniformly distributed in relation to depth in the Savannah River.

In contrast to larval densities, egg densities exhibited significant differences between top and bottom at 12 of 23 transects (Table 3-13). In all cases, bottom densities were higher than top densities. The tendency of the eggs to be concentrated near the bottom was also indicated by average egg density over all dates and transects, which was 48.4 eggs/1000 m^3 near the bottom and 28.1/1000 m^3 near the top. This difference was significant at $p \leq 0.05$.

Greater fish egg densities near the bottom are probably a result of the tendency of eggs to sink through the water column. Larvae, in contrast, can avoid the bottom by swimming. In addition, larvae possess a greater surface area per unit volume than

Table 3-13. Mean top and bottom ichthyoplankton densities in the Savannah River and intake canals. Means underscored by the same line are not significantly different ($p \leq 0.05$) as indicated by t-test. Tests were done on log-transformed data, but means are presented as arithmetic averages. February - July 1985.

River Mile	Mean density of eggs (no./1000 m^3) Top	Bottom	Mean density of larvae (no./1000 m^3) Top	Bottom
89.3	38.0	70.1	14.6	12.9
97.5	23.3	44.5	9.1	11.4
110.0	34.0	54.7	11.0	11.6
120.0	23.9	53.2	16.8	9.8
128.9	37.8	59.6	16.6	15.4
129.1	28.5	46.7	15.9	18.7
137.7	30.4	46.0	17.5	16.5
141.5	21.1	43.5	20.8	16.5
141.7	47.4	70.0	29.1	19.8
145.7	46.5	86.7	25.5	18.4
150.4	22.1	46.2	10.9	10.6
150.8	14.5	23.5	13.3	12.3
152.0	12.0	23.3	13.0	11.7
152.2	15.1	27.3	16.9	14.9
155.2	33.8	45.3	19.9	15.6
155.3[a]	1.6	7.0	31.4	16.7
155.4	34.0	38.4	20.0	14.6
157.0	20.2	39.6	19.4	15.9
157.1[a]	0.1	2.2	22.7	18.0
157.3	50.5	74.8	18.6	19.4
166.6	83.6	107.8	58.2	48.9
176.0	16.0	27.3	45.7	52.8
187.1	12.5	18.4	40.2	46.0
All Transects	28.1	48.4	22.0	19.6

NOTE: RIVIC6 was used to compute the tests presented in this table.

[a]Intake canals.

do eggs, which may facilitate the larvae's support by turbulent currents. The pattern of higher egg density near the bottom was also observed during 1983 and 1984 (Paller et al. 1984).

3.1.2.4 Horizontal Distribution of Ichthyoplankton

The distribution of ichthyoplankton across the river was evaluated by sampling near the South Carolina bank, the Georgia bank, and in mid-river. Larvae and eggs were treated separately because of differences in motility and hydrodynamic characteristics that might affect their horizontal distribution.

Two methods of statistical testing were used to identify horizontal differences in ichthyoplankton density. The first was to compare (by analysis of variance and by Scheffe's tests) density near the Georgia bank, South Carolina bank, and mid-river at each transect during each month of the study. These tests identified horizontal density differences of a relatively short-lived nature. The total number of tests generated by this procedure was fairly large, resulting in a relatively high probability of some significant findings by random chance. We did not consider this a problem, since the principal objective of the test was to identify points of potentially non-uniform distribution for further scrutiny rather than to prove that non-uniform distribution occurred. Transects identified as having lateral differences were examined further to determine if substantive causes, such as larval inputs from major spawning creeks, were responsible for the non-uniform horizontal distribution.

The second testing procedure compared the Georgia bank, mid-river, and South Carolina bank densities at each transect over all dates. These tests provided a summary measure of horizontal density differences at each transect over the entire study period and detected transects where consistent, relatively long-term horizontal density differences occurred.

Tests of horizontal differences in egg density at each transect during each month of study indicated 43 significant differences out of 138 tests (Table 3-14). At a few transects, where ichthyoplankton distributions were highly skewed, the results of tests on log-transformed data do not indicate the same ordering as suggested by comparing arithmetic means. Where such test results are reported (Table 3-14), both arithmetic means and the mean of the log-transformed data are presented (the latter in parentheses) for greater clarity. The most significant horizontal differences in egg density were in April (14) and May (14), when densities were highest; however, some were in March (7) and June (8). Significant differences occurred at all transects, and some transects showed the same horizontal density differences month after month. Further testing indicated that 15 transects exhibited horizontal density differences that were consistent enough to produce a significant finding when the data were grouped across all six months of the study (Table 3-15).

Table 3-14. Savannah River transects with significant ($p \leq 0.05$) differences in egg and larval densities across transects during some months of the study. Means underscored by the same line are not significantly different ($p \leq 0.05$), as indicated by Scheffe's test. Tests were done on log-transformed data, but means are presented as arithmetic averages. February - July 1985.

		Mean density (no./1000 m^3)		
Month	River Mile (RM)	South Carolina bank	Center	Georgia bank
		Eggs		
March	89.3	47.8	75.2	21.6
March	97.5	48.3	23.7	17.9
March	110.0	15.2	33.0	16.5*
March	129.1	9.4	27.8	8.3*
March	141.5	15.3	40.2	0.0
March	145.7	36.7	3.8	3.0
March	155.4	0.0	19.9	3.6
April	89.3	183.7	291.1	137.5
April	97.5	156.0	127.2	57.3
April	120.0	180.1	174.5	45.7
April	129.1	78.7	155.5	114.6*
April	137.7	148.0	153.2	46.9
April	141.5	134.4	139.2	27.1

*An absence of any lines indicates that the ANOVA indicated significant differences, while the range test did not.

Table 3-14. (continued). Savannah River transects with significant ($p \leq 0.05$) differences in egg and larval densities across transects during some months of the study. Means underscored by the same line are not significantly different ($p \leq 0.05$), as indicated by Scheffe's test. Tests were done on log-transformed data, but means are presented as arithmetic averages. February - July 1985.

Month	River Mile (RM)	Mean density (no./1000 m^3) South Carolina bank	Center	Georgia bank
		Eggs (continued)		
April	141.7	257.5	250.2	49.7
April	145.7	319.4	170.8	56.5
April	150.4	112.9	219.3	42.1
April	150.8	43.9	97.4	30.7
April	152.2	89.5 (1.69)**	81.1 (1.89)	31.2 (1.53)
April	155.4	31.5	140.1	36.2
April	157.0	39.8	121.7	131.8
April	187.1	26.2	13.4	6.1*
May	89.3	78.7	90.9	40.6*
May	97.5	80.2	48.2	16.8
May	120.0	101.9	87.9	27.9
May	128.9	67.3	112.5	44.2
May	129.1	24.4	112.8	56.9

*An absence of any lines indicates that the ANOVA indicated significant differences while the range test did not.

**Mean of the $\log_{10}$-transformed data.

Table 3-14. (continued). Savannah River transects with significant ($p \leq 0.05$) differences in egg and larval densities across transects during some months of the study. Means underscored by the same line are not significantly different ($p \leq 0.05$), as indicated by Scheffe's test. Tests were done on log-transformed data, but means are presented as arithmetic averages. February - July 1985.

		Mean density (no./1000 m^3)		
Month	River Mile (RM)	South Carolina bank	Center	Georgia bank
		Eggs (continued)		
May	137.7	96.0	74.4	29.6
May	141.5	54.7	85.4	15.7
May	141.7	107.4	125.2	38.8
May	145.7	195.9	158.2	55.2
May	150.4	34.8	75.5	13.6
May	150.8	34.4 (1.43)**	37.3 (1.57)	11.6 (1.23
May	157.0	22.5	57.4	63.8
May	157.3	39.2	89.3	72.0
May	166.6	163.3	260.8	122.2
June	97.5	31.0	11.2	3.9
June	137.7	33.3	11.4	10.4
June	141.7	52.9	39.6	5.3
June	145.7	98.5	47.6	15.2

**Mean of the $\log_{10}$-transformed data.

Table 3-14. (continued). Savannah River transects with significant ($p \leq 0.05$) differences in egg and larval densities across transects during some months of the study. Means underscored by the same line are not significantly different ($p \leq 0.05$), as indicated by Scheffe's test. Tests were done on log-transformed data, but means are presented as arithmetic averages. February - July 1985.

Month	River Mile (RM)	Mean density (no./1000 m^3) South Carolina bank	Center	Georgia bank
		Eggs (continued)		
June	150.8	5.4	34.0	11.0
June	157.0	5.5	21.9	19.7
June	176.0	19.5	56.2	15.4
June	187.1	18.8	28.6	4.8
		Larvae		
February	141.5	3.5	0.0	0.0*
April	155.3[a]	24.5 (1.44)**	27.5 (1.38)	98.7 (1.88
April	157.1[a]	48.7	25.4	72.7
April	141.5	35.5 (1.56)	51.8 (1.67)	18.0 (1.34)
April	141.7	38.2 (1.59)	93.3 (1.84)	32.8 (1.49)
April	150.4	2.9	16.7	30.8

[a] Intake canals. The two banks are north and south of the canal.
*An absence of any lines indicates that the ANOVA indicated significant differences, while the range test did not.
** Mean of the $\log_{10}$-transformed data.

Table 3-14. (continued). Savannah River transects with significant ($p \leq 0.05$) differences in egg and larval densities across transects during some months of the study. Means underscored by the same line are not significantly different ($p \leq 0.05$), as indicated by Scheffe's test. Tests were done on log-transformed data, but means are presented as arithmetic averages. February - July 1985.

		Mean density (no./1000 m^3)		
Month	River Mile (RM)	South Carolina bank	Center	Georgia bank
		Larvae (continued)		
May	155.3[a]	63.2	64.0	122.8*
May	155.2	79.0	65.8	44.9*
May	187.1	261.0	203.8	102.2
June	187.1	66.9	28.1	79.5
July	187.1	21.4	0.0	20.2

NOTE: RIVIC4 and RIVIC6 were used to compute the tests presented in this table.

[a] Intake canals. The two banks are north and south of the canal.
* An absence of any lines indicates that the ANOVA indicated significant differences, while the range test did not.

Table 3-15. Mean ichthyoplankton densities near the Georgia bank, the South Carolina bank, and in the center of the Savannah River at each transect over all months of the study. Means underscored by the same line are not significantly different ($p \leq 0.05$), as indicated by Scheffe's test. Tests were done on log-transformed data, but means are presented as arithmetic averages. February - July 1985.

River Mile	Mean density of eggs (no./1000 m^3)			Mean density of larvae (no./1000 m^3)		
	SC bank	Center	GA bank	SC bank	Center	GA bank
89.3	53.6	75.5	33.1	16.2	12.1	13.0
97.5	52.1	34.2	15.4	12.4	8.0	10.3
110.0	29.9	62.9	40.2	9.7	11.5	12.8
120.0	52.4	48.5	14.8	19.2	10.1	10.5*
128.9	27.2	69.3	49.7	13.5	18.1	16.4
129.1	22.2	54.7	35.9	16.4	16.7	19.0
137.7	52.9	45.8	15.8	18.8	13.9	18.4
141.5	38.7	49.0	9.1	17.3	22.2	16.4
141.7	78.1	80.0	18.0	21.4	33.2	18.8
145.7	112.4	65.2	22.1	19.2	26.7	20.0
150.4	30.6	59.7	12.1	6.0	10.3	15.9
150.8	15.2	32.0	9.8	8.9	13.0	16.5
152.0	16.2	21.4	15.3	9.6	11.2	16.3
152.2	21.6	29.7	12.3	17.1	13.6	17.0
155.2	36.4	49.2	33.1	18.4	18.6	16.3

*An absence of lines indicates that the ANOVA indicated significant differences, while the range test did not.

Table 3-15. (continued). Mean ichthyoplankton densities near the Georgia bank, the South Carolina bank, and in the center of the Savannah River at each transect over all months of the study. Means underscored by the same line are not significantly different ($p \leq 0.05$), as indicated by Scheffe's test. Tests were done on log-transformed data, but means are presented as arithmetic averages. February - July 1985.

River Mile	Mean density of eggs (no./1000 m^3)			Mean density of larvae (no./1000 m^3)		
	SC bank	Center	GA bank	SC bank	Center	GA bank
155.3[a]	0.0	4.8	2.3	23.0	21.9	44.2
155.4	22.9	53.4	32.4	22.5	16.1	13.2
157.0	13.3	36.7	39.7	22.4	16.5	14.1
157.1[a]	0.0	1.1	0.4	17.8	19.4	29.7
157.3	74.0	80.4	33.5	18.5	19.5	18.9
166.6	69.6	149.0	68.5	67.3	46.5	46.9
176.0	17.8	30.6	16.6*	50.0	41.7	56.1
187.1	23.1	16.0	7.3*	57.9	37.5	33.9
All transects	39.1	50.0	24.4	22.0	19.9	20.8

NOTE: RIVIC6 was used to compute the tests presented in this table.

*An absence of lines indicates that the ANOVA indicated significant differences, while the range test did not.

While the specific causes of most of the horizontal differences in egg density observed during 1985 are unknown, it can be inferred that they were due to the uneven distribution of American shad eggs, since these eggs constituted 75.7% of all eggs in the river (Table 3-16). Uneven distribution of American shad eggs may be due to localized spawning or to eddies and currents that concentrated American shad eggs in mid-river or along the river banks. Uneven horizontal distribution of fish eggs was also observed during 1983 and 1984 (Paller et al. 1984, 1985). There was no evidence during any year of this study of low egg densities near the South Carolina bank in the region where SRP thermal discharges occur (RM 150.4 and 152.0; Paller et al. 1984, 1985).

Fish larval densities were subjected to the same testing procedures as fish eggs. Tests of horizontal differences in larval density at each transect during each month of the study identified 11 significant differences (Table 3-14). Substantive causes for the 11 cases in which significant horizontal differences occurred were generally lacking, with two exceptions. The occurrence of significantly higher densities on the South Carolina bank at RM 141.5 in February was probably due to ichthyoplankton transported from Steel Creek. Ichthyoplankton densities in Steel Creek (mean of 11.6/1000 m^3) were higher than in the river above Steel Creek (0.0/1000 m^3) during February, resulting in strong ichthyoplankton contributions from the creek to the river.

Table 3-16. Percent abundance of fish eggs in the Savannah River, selected Savannah River tributaries, selected river oxbows and SRP intake canals. February - July 1985.

Taxa	Savannah River	Tributary Creeks	River Oxbows	Intake Canals
blueback herring	2.3	26.9	0.9	0.0
American shad	75.7	17.4	1.9	13.6
gizzard and/or threadfin shad	1.7	3.3	63.0	0.0
minnow (Cyprinidae)	0.3	0.0	0.9	0.0
striped bass	7.2	0.4	5.6	77.3
yellow perch	0.3	1.9	0.0	0.0
other	12.6	50.1	27.8	9.1
Total Percent	100.1	100.0	100.1	100.0
Total Number	15058	539	108	44

NOTE: RIVIC1 was used to compute the data presented in this table.

The second potentially important horizontal difference in larval density occurred at RM 150.4, where thermal discharge from Four Mile Creek (RM 150.6) flows near the South Carolina bank of the river. Larval densities were significantly lower near the South Carolina bank (2.9/1000 m^3) than in the center (16.7/1000 m^3) or near the Georgia bank (30.8/1000 m^3) at RM 150.4 during April (Table 3-14).

To determine the cause of the horizontal density pattern at RM 150.4, larval densities near the South Carolina bank at RM 150.4 were compared to larval densities near the South Carolina bank at RM 150.8. The objective of this comparison was to determine whether there was an actual reduction in larval density between RM 150.4 and RM 150.8 or whether the low density at RM 150.4 was merely the continuation of a pattern already established farther upstream. Mean density over the entire study period was 6.0/1000 m^3 near the South Carolina bank at RM 150.4 and 8.9/1000 m^3 near the South Carolina bank at RM 150.8 (Table 3-15). These numbers suggest that larval densities were reduced on the South Carolina side during the passage from RM 150.8 to RM 150.4. More resolution on this density reduction was obtained by comparing densities between RM 150.4 and 150.8 on a date-by-date basis (Table 3-17). This comparison indicated that densities on the South Carolina side decreased by up to 100% between RM 150.8 and 150.4 on the April sample dates. Density reductions occurred both near the top and near the bottom during April. Lesser

Table 3-17. Density (no./1000 m^3) of fish larvae and temperature (°C) near the surface and near the bottom along the South Carolina bank of the Savannah River at RM 150.4 and 150.8, that bracket the mouth of Four Mile Creek which receives thermal effluent from C-Reactor. February - July 1985.

	Density (no./1000 m^3)				Temperature (°C)			
	RM 150.8		RM 150.4		RM 150.8		RM 150.4	
Date	Near surface	Near bottom	Near surface	Near bottom	Near surface	Near bottom	Near surface	Near bottom
2/05	0.0	0.0	0.0	0.0	-	-	-	-
2/12	0.0	0.0	0.0	0.0	7.0	6.9	7.8	7.8
2/19	0.0	0.0	0.0	0.0	8.1	7.8	9.8	9.1
2/26	0.0	0.0	0.0	0.0	12.5	12.0	13.0	12.5
3/05	0.0	0.0	0.0	0.0	12.5	12.5	13.0	13.0
3/12	0.0	0.0	8.5	0.0	13.5	13.5	17.5	16.0
3/19	0.0	0.0	0.0	9.1	11.0	10.5	10.5	10.0
3/26	0.0	0.0	0.0	0.0	13.9	13.8	16.2	15.7
4/02	26.3	11.1	0.0	0.0	16.5	16.5	17.5	17.5
4/09	42.9	9.3	7.2	0.0	15.5	15.5	17.5	17.5
4/16	0.0	7.1	0.0	0.0	16.5	16.5	20.0	17.5
4/23	0.0	0.0	0.0	0.0	19.5	19.5	22.0	21.5
4/30	40.6	21.2	14.6	6.9	20.0	20.0	22.0	22.0
5/07	0.0	29.2	9.1	8.0	18.5	18.0	19.5	19.5
5/14	38.4	51.0	10.1	44.2	21.0	21.0	23.0	22.5
5/21	13.3	52.0	20.3	73.6	21.5	21.5	22.5	22.5
5/28	58.7	25.3	27.2	29.4	22.0	22.0	22.5	22.5
6/04	9.6	18.9	7.9	8.0	24.0	24.0	24.5	24.5
6/11	0.0	0.0	0.0	10.5	24.5	24.5	26.0	25.5
6/18	0.0	8.0	0.0	0.0	23.0	23.0	24.0	24.0
6/25	0.0	0.0	0.0	0.0	22.0	22.0	22.0	22.0
7/02	0.0	0.0	8.9	0.0	23.0	23.0	22.5	22.5
7/09	0.0	0.0	0.0	8.5	22.5	22.5	22.3	22.0
7/16	0.0	0.0	0.0	0.0	24.0	24.0	24.0	24.0
7/23	0.0	0.0	0.0	0.0	24.6	24.6	24.8	24.7
7/30	0.0	0.0	0.0	0.0	22.5	22.5	23.0	22.5

NOTE: RIVIC8 was used to compute the data presented in this table.

density reductions at RM 150.4 also occurred during May and early June.

C-Reactor was operating throughout the April, May, and early June period, when density reductions occurred on the South Carolina side between RM 150.4, as indicated by elevated temperatures at RM 150.4, while temperatures recorded at RM 150.4 were generally only several degrees above ambient (Table 3-17). It is important to recognize that these temperatures are not a measure of maximum water temperature near the mouth of Four Mile Creek. Thermal-imagery studies have shown that temperatures in the Four Mile Creek thermal plume are spatially variable and can be in excess of $10^{o}C$ higher directly in front of the creek mouth (RM 150.6) than in the river immediately upstream (Shines and Tinney 1983). Thus, fish drifting past the mouth of Four Mile Creek may have been exposed to considerably warmer temperatures than indicated in Table 3-17.

There are at least two possible explanations for the reductions in the density of fish larvae between RM 150.4 and 150.8. One is the displacement and/or dilution of relatively "larvae rich" water in the river with "larvae poor" water from Four Mile Creek (larval densities in the mouth of Four Mile Creek were zero or very low throughout the study period). This does not presuppose larval mortality in order to account for the density reduction. The second mechanism involves an actual loss of larvae from the water column, due either to mortality and subsequent settling to the bottom or possibly, in the case of more strongly swimming larvae, to avoidance of the plume area. If dilution and/or displacement is the mechanism, all taxa would be expected to show about the same density reduction. If thermal impact is the mechanism, more temperature sensitive larvae might undergo density reductions, though the density of less sensitive types might be unaffected.

An analysis of density changes between RM 150.4 and RM 150.8 for each larval species showed that the density reduction between transects was due almost solely to the absence of spotted sucker larvae. The density of spotted sucker larvae at RM 150.8 averaged 12.9, 7.1, and 2.4/1000 m^3 during the months of April, May, and June, respectively (the only months when larvae were collected from RM 150.4 and 150.8 in substantial numbers; Table 3-18). Comparable values at RM 150.4 were 0.7, 2.4, and 0.0/1000 m^3. The density of other types of larvae did not undergo such reductions between transects. Average gizzard and/or threadfin shad densities during April, May, and June were 0.8, 13.8, and 2.2/1000 m^3, respectively, at RM 150.8; and 0.7, 8.9, and 1.0/1000 m^3 at RM 150.4. Average sunfish densities during April, May, and June respectively, were 0.0, 0.0, and 0.0/1000 m^3 at RM 150.8; and 1.4, 1.0, and 0.0/1000 m^3 at RM 150.4. Average carp densities during April, May, and June, respectively, were 0.0, 7.6, and 0.0/1000 m^3 at RM 150.8; and 0.0, 10.0, and 1.3/1000 m^3 at RM 150.4.

Table 3-18. Density (no./1000 m^3) of fish larvae by taxa near the South Carolina bank of the Savannah River at RM 150.4 and 150.8 during April, May, and June 1985. RM 150.4 and RM 150.8 bracket the mouth of Four Mile Creek, which receives thermal effluent from C-Reactor. Only April, May, and June are shown, since nearly all the larvae were collected during these months. February - July 1985.

	April					
RM 150.8	4/02	4/09	4/16	4/23	4/30	April mean
unid. Clupeidae	0.0	0.0	0.0	0.0	0.0	0.0
gizzard and/or threadfin shad	0.0	0.0	0.0	0.0	4.2	0.8
minnow	0.0	0.0	0.0	0.0	0.0	0.0
carp	0.0	0.0	0.0	0.0	0.0	0.0
spotted sucker	18.7	26.1	0.0	0.0	19.7	12.9
sunfish	0.0	0.0	0.0	0.0	0.0	0.0
unidentified	0.0	0.0	3.6	0.0	7.1	2.1
Total	18.7	26.1	3.6	0.0	31.0	15.8
RM 150.4						
unid. Clupeidae	0.0	0.0	0.0	0.0	0.0	0.0
gizzard and/or threadfin shad	0.0	0.0	0.0	0.0	3.7	0.7
minnow	0.0	0.0	0.0	0.0	0.0	0.0
carp	0.0	0.0	0.0	0.0	0.0	0.0
spotted sucker	0.0	0.0	0.0	0.0	3.5	0.7
sunfish	0.0	3.1	0.0	0.0	3.7	1.4
unidentified	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	3.1	0.0	0.0	10.9	2.8

Table 3-18. (continued). Density (no./1000 m^3) of fish larvae by taxa near the South Carolina bank of the Savannah River at RM 150.4 and 150.8 during April, May, and June 1985. RM 150.4 and RM 150.8 bracket the mouth of Four Mile Creek, which receives thermal effluent from C-Reactor. Only April, May, and June are shown, since nearly all the larvae were collected during these months. February - July 1985.

	May				
RM 150.8	5/07	5/14	5/21	5/28	May mean
unid. Clupeidae	0.0	0.0	0.0	4.3	1.1
gizzard and/or threadfin shad	7.3	9.0	18.0	20.9	13.8
minnow	0.0	4.3	0.0	0.0	1.1
carp	0.0	14.0	3.8	12.6	7.6
spotted sucker	7.4	9.1	7.5	4.3	7.1
sunfish	0.0	0.0	0.0	0.0	0.0
unidentified	0.0	8.5	3.3	0.0	3.0
Total	14.7	44.9	32.6	42.1	33.6
RM 150.4					
unid. Clupeidae	4.6	0.0	13.4	4.6	5.7
gizzard and/or threadfin shad	4.0	13.3	13.2	4.9	8.9
minnow	0.0	0.0	0.0	0.0	0.0
carp	0.0	4.5	16.4	18.9	10.0
spotted sucker	0.0	9.5	0.0	0.0	2.4
sunfish	0.0	0.0	4.1	0.0	1.0
unidentified	0.0	0.0	0.0	0.0	0.0
Total	8.6	27.3	47.1	28.4	27.9

Table 3-18. (continued). Density (no./1000 m^3) of fish larvae by taxa near the South Carolina bank of the Savannah River at RM 150.4 and 150.8 during April, May, and June 1985. RM 150.4 and RM 150.8 bracket the mouth of Four Mile Creek, which receives thermal effluent from C-Reactor. Only April, May, and June are shown, since nearly all the larvae were collected during these months. February - July 1985.

	June				
RM 150.8	6/04	6/11	6/18	6/25	June mean
unid. Clupeidae	0.0	0.0	0.0	0.0	0.0
gizzard and/or threadfin shad	4.8	0.0	4.0	0.0	2.2
minnow	0.0	0.0	0.0	0.0	0.0
carp	0.0	0.0	0.0	0.0	0.0
spotted sucker	9.5	0.0	0.0	0.0	2.4
sunfish	0.0	0.0	0.0	0.0	0.0
unidentified	0.0	0.0	0.0	0.0	0.0
Total	14.3	0.0	4.0	0.0	4.6
RM 150.4					
unid. Clupeidae	0.0	0.0	0.0	0.0	0.0
gizzard and/or threadfin shad	4.0	0.0	0.0	0.0	1.0
minnow	0.0	0.0	0.0	0.0	0.0
carp	0.0	5.3	0.0	0.0	1.3
spotted sucker	0.0	0.0	0.0	0.0	0.0
sunfish	0.0	0.0	0.0	0.0	0.0
unidentified	4.0	0.0	0.0	0.0	1.0
Total	8.0	5.3	0.0	0.0	3.1

NOTE: RIVIC8 was used to compute the data presented in this table.

Spotted sucker larvae were more abundant during 1985 (10.8% of all larvae) than during 1983 (5% of all larvae) or 1984 (3.3% of all larvae). Because they were a major component of the ichthyoplankton collected at RM 150.4 and 150.8 during 1985, their absence caused a significant change in overall ichthyoplankton abundance at RM 150.4. In earlier years, there were no obvious reductions in ichthyoplankton abundance near the South Carolina bank between RM 150.8 and 150.4, possibly because spotted suckers were comparatively rare and any losses among this species would have been overshadowed by the high variability typical of ichthyoplankton density data. Another factor that may have contributed to the ichthyoplankton losses observed below Four Mile Creek (i.e., at RM 150.4) during 1985 was low river level. River levels were lower during 1985 than during 1983 and 1984. During 1983 and 1984, the Savannah River flooded its banks for extended periods (Paller et al. 1984, 1985), causing the Four Mile Creek plume to disperse and cool in the floodplain prior to entering the river.

We could find no information in the literature concerning the temperature tolerances of spotted suckers. Previous field studies on the SRP indicate that spotted suckers avoided the thermal creeks to a greater extent than did most species, suggesting sensitivity to high temperatures (Paller et al. 1985). In addition, spotted sucker larvae have been particularly abundant in Lower Three Runs Creek, the coolest of the SRP creeks (Paller 1984; Paller et al. 1985). Spotted suckers are common in the Savannah River (Paller et al. 1984, 1985) and widely distributed in eastern

North America (Scott and Crossman 1973). They have limited ecological importance when young as forage fish for predatory species, but have little or no economic or recreational importance.

The preceding data indicate that the statistically significant decrease in ichthyoplankton density at RM 150.4 was due to a decrease in the density of spotted sucker larvae. Such a decrease could be due to mortality, avoidance, various unidentified factors, or random chance. It is important to note that the number of spotted sucker larvae upon which the April, May, and June density estimates at RM 150.8 were based was approximately 12 - 15. Thus, the number of ichthyoplankters included in the analysis is small. For better understanding of the influence of Four Mile Creek discharge, we recommend future studies incorporating more sample stations in the vicinity of RM 150.4, live table techniques for separating dead from living larvae, and laboratory studies to assess the temperature tolerances of the larvae of potentially sensitive species such as the spotted sucker.

3.1.2.5 Spatial and Temporal Distribution of Ichthyoplankton

Localized changes in river ichthyoplankton density were identified by averaging data from each transect on a monthly basis and comparing (with t-tests) the mean monthly density at each transect with the monthly mean density at each neighboring transect. This analysis was designed to identify locations in the river where ichthyoplankton densities changed significantly due to such factors as inputs from local spawning areas or losses due to environmental disturbances. This procedure generated 23 t-tests for each month of sampling. Multiple-testing procedures of this sort that involve repeated testing of the same data are susceptible to a high Type I error rate due to the occurrence of false significant findings by random chance. To avoid this problem, Boniferoni's inequality theorem (SAS 1982) was used to calculate a corrected critical level for each test as follows:

$$T = F/K$$

where T is the corrected critical level for each test in the group of multiple tests, F is the critical level applying to the entire test group, and K is the number of tests.

The corrected critical level applicable to each t-test in the group of 23 tests was 0.0022 (i.e., 0.05/23). Use of this critical level for each individual test reduced the error rate for the entire group of 23 tests to $p \leq 0.05$. In contrast, an uncorrected critical level of $p \leq 0.05$ for each individual test would have made the probability of a type I error (i.e., acceptance of a false significant finding; Sokal and Rohlf 1981) in the entire group of 23 tests much higher than $p \leq 0.05$. Type I errors involving differences between river transects in the vicinity of the SRP could lead to false conclusions about the impacts of the SRP on river ichthyoplankton. An alpha level correction was not applied to the horizontal and vertical distribution tests (Section 3.1.2.3 and 3.1.2.4) because each transect was evaluated separately in the procedures. In the spatial distribution tests used in this section, however, all 23 tests are linked together, since density at each transect was evaluated by comparing it with densities at the preceding and following transects.

In addition to the tests described above, broader trends in ichthyoplankton density were evaluated by comparing the monthly averages at lower farfield transects, nearfield transects, and upper farfield transects. Analysis of variance and Scheffe's tests were used to make these comparisons; test results were considered significant at an uncorrected probability of $p \leq 0.05$. For the purpose of all statistical comparisons made in this section, fish eggs and larvae were combined into total ichthyoplankton.

Ichthyoplankton was collected in small numbers at all of the transects in the lower farfield and at some of the transects in the nearfield and upper farfield during February (Figure 3-7; Table 3-19). While there was an absence of statistically significant differences between adjacent transects during February, total ichthyoplankton densities below RM 141.7 (0.0 - 1.2/1000 m^3) were higher than those above (0.0 - 0.4/1000 m^3). This may have been related to slightly warmer temperatures below RM 141.7 (8.8 - 9.4°C, compared with 7.8 - 9.2°C above RM 141.7). Mean ichthyo-

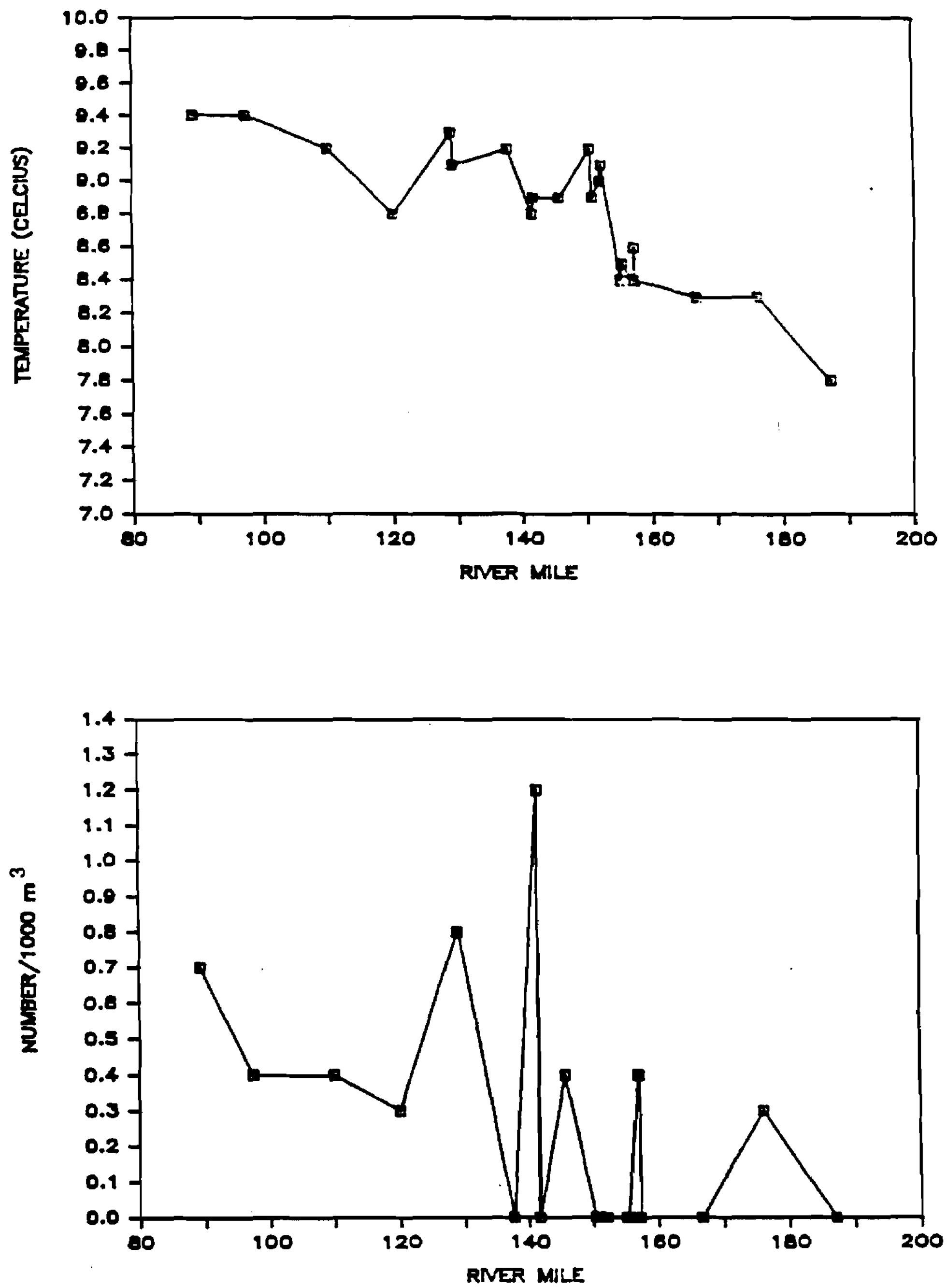


Figure 3-7. Mean ichthyoplankton density (no./1000 m^3) and mean temperature (°C) at Savannah River transects during February (RIVIC18). February - July 1985.

Table 3-19. Mean ichthyoplankton densities (no./1000 m^3) and temperatures (°C) at Savannah River transects during February 1985.

River Mile	Temp (°C)	American shad	blue-back herring	striped bass	other shad[a]	unid. Clupeidae	minnows (Cyprinidae)	spotted suckers	sunfish	crappie	Total ichthyo-plank-ton[b]
						Lower Farfield					
89.3	9.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
97.5	9.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
110.0	9.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4
120.0	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
						Nearfield					
128.9	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
129.1	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
137.7	9.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
141.5	8.8	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	1.2
141.7	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
145.7	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
150.4	9.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150.8	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
152.0	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
152.2	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
155.2	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
155.3[c]	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
155.4	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
157.0	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
157.1[c]	8.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
157.3	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
						Upper Farfield					
166.6	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
176.0	8.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3
187.1	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

NOTE: RIVIC18 was used to compute the data presented in this table.
TTEST85 was used to compare density differences between transects.

[a] Gizzard and/or threadfin shad.

[b] Totals include taxa shown plus taxa not shown.

[c] Intake canals.

plankton density was higher in the lower farfield (0.5/1000 m^3) than in the upper farfield (0.2/1000 m^3) or nearfield (0.2/1000 m^3; Table 3-20) during February, although the difference was not significant at $p \leq 0.05$.

Some of the ichthyoplankton (principally darters) collected below RM 141.7 during February were probably transported into the river from Steel Creek at RM 141.6. Ichthyoplankton densities averaged 11.6/1000 m^3 in Steel Creek during February 1985, compared with 0.0/1000 m^3 at the river transect just above Steel Creek (RM 141.7). It is possible that the relatively high densities observed in Steel Creek during February were the result of slightly accelerated spawning because of elevated swamp temperatures. The mean temperature in Steel Creek during February was 10.5°C (Figure 3-4), compared with 8.9°C (Table 3-19) at the river transect immediately above Steel Creek. This slight temperature elevation was probably due to insolation rather than SRP activities. Steel Creek does not receive thermal discharge unless Pen Branch water flows into the Steel Creek delta, which occurs only when the Savannah River is high enough to inundate the floodplains (approximately 91 feet; Scott et al., in press). The Savannah River was below flood stage during all of the February - July sample period except for a few days in early February.

Ichthyoplankton densities in the Savannah River increased during March, ranging from a mean of 0.7 organisms/1000 m^3 at RM 187.1 to a mean of 55.7/1000 m^3 at RM 89.3 (Figure 3-8; Table 3-

Table 3-20. Mean ichthyoplankton densities at upper farfield (RM 166.6 - 187.1), nearfield (RM 128.9 - 157.3, excluding intake canals), and lower farfield (RM 89.3 - 120.0) Savannah River transects. Means were analyzed with Scheffe's test. Tests were conducted on transformed data [$x_1 = \log_{10}(x + 10)$], but mean densities shown are arithmetic averages. Means underscored by same line are not significantly different ($p \leq 0.05$). February - July 1985.

	Mean density (no./1000m^3)			
Month	Upper farfield	Nearfield	Lower farfield	Grand Mean
February	0.2	0.3	0.5	0.3
March	2.0	16.5	36.5	18.2
April	134.9	150.7	193.6	156.6
May	297.4	119.6	90.4	139.4
June	122.0	34.8	11.7	42.9
July	11.1	2.5	1.1	3.5
February - July	92.9	56.7	54.8	61.5

NOTE: RIVTRAN1 and RIVIC5a were used to compute the tests presented in this table.

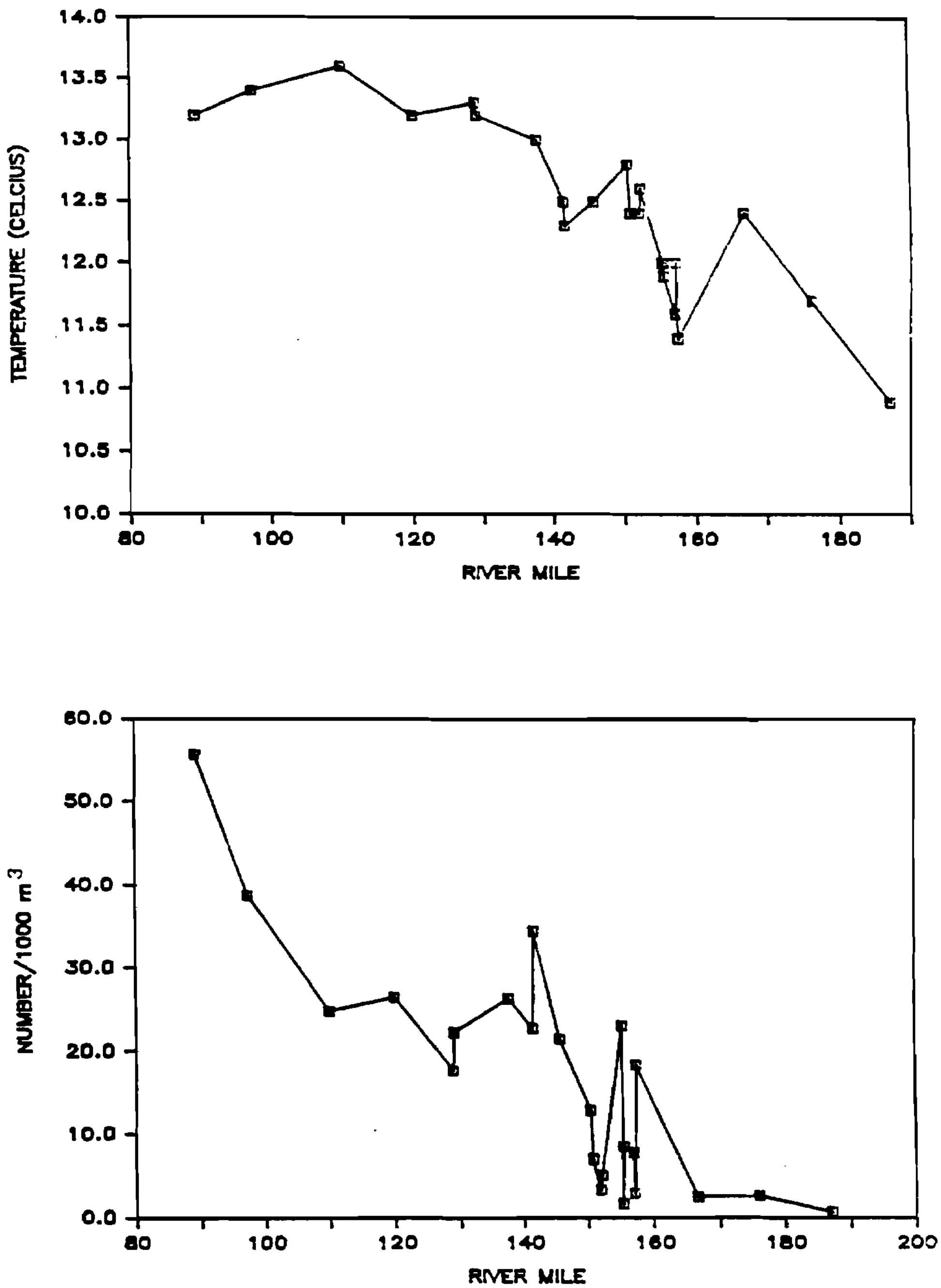


Figure 3-8. Mean ichthyoplankton density (no./1000 m^3) and mean temperature (°C) at Savannah River transects during March (RIVIC18). February - July 1985.

21). This increase was associated with rising temperatures that averaged 12.5°C over all the river sample stations during March, compared with an average of 8.8°C during February. Spatial trends in ichthyoplankton density were similar to those in February, with lowest densities in the upper farfield (mean of 2.0/1000 m^3), intermediate densities in the nearfield (mean of 16.5/1000 m^3), and highest densities in the lower farfield (mean of 36.5/1000 m^3; Table 3-20). Density differences between the regions were significant at $p \leq 0.05$. This density trend was associated with a temperature gradient in the Savannah River. Mean temperature increased from 10.9°C at RM 187.1 to 13.6°C at RM 89.3, and was directly correlated with mean ichthyoplankton density ($r = 0.57$; $p \leq 0.05$). Another factor that contributed to the low densities in the upper farfield was a lack of American shad ichthyoplankton. Average American shad densities at river transects upstream from RM 157.3 ranged from 0.0 - 1.2/1000 m^3, compared with 2.4 - 34.8/1000 m^3 at the river transects (excluding the intake canals; Table 3-21) downstream from RM 157.3.

Statistically significant changes in ichthyoplankton density occurred between two sets of adjacent transects during March (Table 3-21). Ichthyoplankton density at RM 157.3 (18.4/1000 m^3) was significantly higher than at RM 166.6 (2.5/1000 m^3), and ichthyoplankton density in the 1G intake canal (RM 157.1, 2.9/1000 m^3) was significantly lower than at the river transect just upstream from it (RM 157.3, 18.4/1000 m^3). The density difference between RM 157.3 and 166.6 was due to fewer American

Table 3-21. Mean ichthyoplankton densities (no./1000 m^3) and temperatures (°C) at Savannah River transects during March 1985.

River Mile	Temp (°C)	American shad	blue-back herring	striped bass	other shad[a]	unid. Clupeidae	minnows (Cyprinidae)	spotted suckers	sunfish	crappie	Total ichthyo-plankton[b]
					Lower Farfield						
89.3	13.2	34.8	0.8	0.4	0.3	1.9	0.3	0.4	1.5	0.0	55.7
97.5	13.4	20.6	0.4	0.0	0.0	4.5	0.3	0.0	0.4	0.3	38.8
110.0	13.6	14.9	0.0	0.0	0.0	0.6	0.3	0.0	0.0	0.4	24.9
120.0	13.2	22.6	0.6	0.0	0.0	0.0	0.0	0.0	0.4	0.0	26.6
					Nearfield						
128.9	13.3	11.2	0.3	0.0	0.0	0.7	1.3	0.0	0.7	0.7	17.7
129.1	13.2	12.2	0.4	0.0	0.0	0.0	0.0	0.0	1.5	0.3	22.3
137.7	13.0	12.5	0.4	0.0	0.0	0.0	1.3	0.4	2.1	0.0	26.4
141.5	12.5	15.0	1.4	0.0	0.0	0.2	0.9	0.0	0.7	0.4	22.8
141.7	12.3	24.4	0.0	0.0	0.0	0.4	4.3	0.0	2.2	0.7	34.5
145.7	12.5	14.2	0.0	0.0	0.0	0.0	1.8	0.4	1.5	1.5	21.5
150.4	12.8	11.5	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	12.9
150.8	12.4	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
152.0	12.4	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.3
152.2	12.6	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
155.2	12.0	7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	23.1
155.3[c]	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.5	1.7
155.4	11.9	7.8	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	8.5
157.0	11.6	6.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.8
157.1[c]	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.9*
157.3	11.4	15.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	18.4*
					Upper Farfield						
166.6	12.4	1.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	2.5*
176.0	11.7	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	2.7
187.1	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7

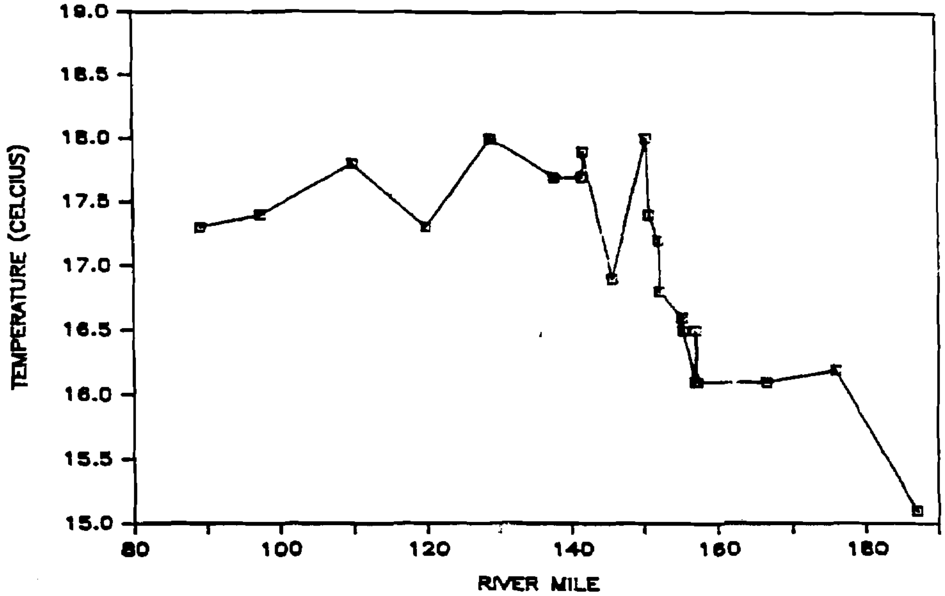
NOTE: RIVIC18 was used to compute the data presented in this table.
TTEST85 was used to compare density differences between transects.

[a] Gizzard and/or threadfin shad.
[b] Totals include taxa shown plus taxa not shown.
[c] Intake canals.
* Density values separated by asterisks are significantly different from each other at $p \leq 0.0022$.

shad spawning above RM 157.3. The low average density in the 1G intake canal was largely due to an absence of American shad ichthyoplankton in the canal. The same situation occurred at the 3G canal (RM 155.3), although the difference between it and the neighboring river transects was not great enough to be statistically significant. The lack of American shad ichthyoplankton in the intake canals is probably due to the tendency of American shad eggs to settle to the bottom in the slow currents in the intake canals (McFarlane 1983). Shad eggs that settle to the bottom probably suffocate in the bottom sediment. Another possible reason for low American shad densities in the intake canals is that the intake canals do not present the riverine spawning conditions that shad prefer (Leggett 1976).

The low ichthyoplankton densities in the intake canals during March 1985 (1.7 and 2.9/1000 m^3: 3G and 1G canals, respectively) contrast with the high densities in the intake canals during March 1984 (37.0 and 54.3/1000 m^3: 3G and 1G canals, respectively; Paller et al. 1985). Most of the ichthyoplankton in the intake canals during March 1984 were crappie larvae. Crappie larvae were scarce throughout the Savannah River during 1985.

Ichthyoplankton densities averaged 156.6 organisms/1000 m^3 throughout the entire river study area (excluding the intake canals) during April (Figure 3-9; Table 3-22), suggesting a 9-fold increase in spawning activity after March (mean of 18.2/1000 m^3). This increase was associated with water temperatures that in-



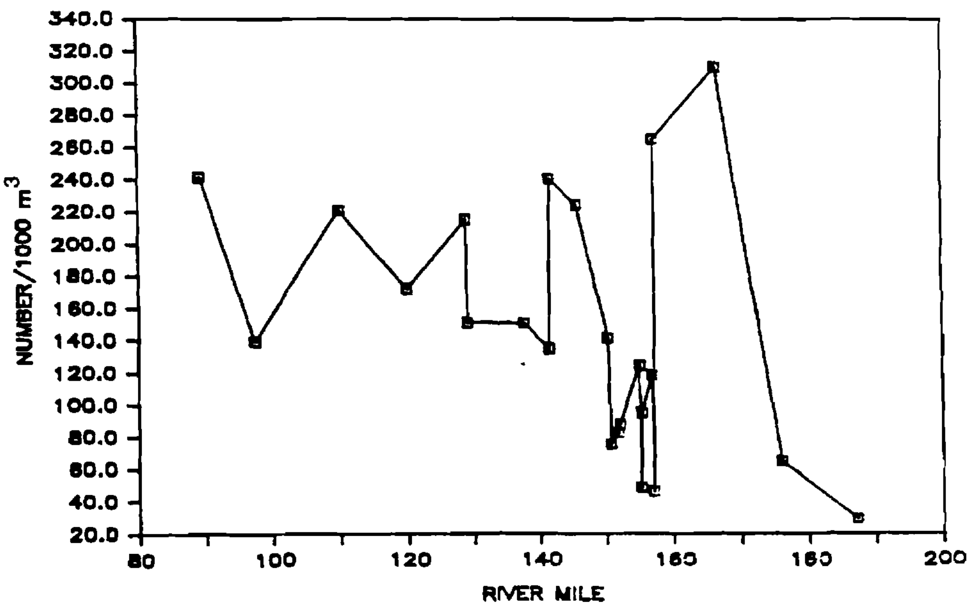


Figure 3-9. Mean ichthyoplankton density (no./1000 m^3) and mean temperature (°C) at Savannah River transects during April (RIVIC18). February - July 1985.

Table 3-22. Mean ichthyoplankton densities (no./1000 m^3) and temperatures (^oC) at Savannah River transects during April 1985.

River Mile	Temp (^oC)	American shad	blue-back herring	striped bass	other shad[a]	unid. Clupeidae	minnows (Cyprinidae)	spotted suckers	sunfish	crappie	Total ichthyo-plankton[b]
						Lower Farfield					
89.3	17.3	185.5	3.2	5.5	1.9	2.0	10.3	15.8	1.3	0.9	241.9*
97.5	17.4	101.1	5.0	6.7	2.7	1.0	3.1	10.8	0.4	0.0	139.5*
110.0	17.8	169.7	2.7	9.4	0.0	0.9	8.3	11.9	0.0	0.5	220.9
120.0	17.3	120.3	2.4	8.3	0.7	9.4	5.5	14.5	1.4	2.2	172.1
						Nearfield					
128.9	18.0	151.5	1.6	17.9	1.7	0.0	14.3	15.8	3.0	0.0	215.5
129.1	18.0	91.7	1.1	14.4	0.0	1.7	10.9	12.4	5.4	0.9	151.3
137.7	17.7	104.8	7.0	1.3	0.5	0.8	5.4	21.0	2.8	0.0	150.9
141.5	17.7	94.5	3.2	0.6	0.3	0.6	2.8	25.5	1.5	0.2	135.3*
141.7	17.9	170.4	2.3	2.8	2.8	0.0	3.9	45.1	1.4	0.9	240.6*
145.7	16.9	170.7	2.3	2.9	0.8	0.2	1.1	35.4	1.3	0.3	224.3
150.4	18.0	69.5	2.3	12.6	0.8	0.0	0.5	14.2	0.5	0.5	141.5
150.8	17.4	37.5	3.6	1.8	1.4	0.2	0.5	15.4	0.3	0.0	75.7
152.0	17.2	35.9	2.6	19.1	3.1	0.9	2.4	13.2	0.0	0.0	82.8
152.2	16.8	52.2	3.2	8.9	0.9	0.5	0.9	17.1	0.0	0.4	88.1
155.2[c]	16.6	58.6	11.5	27.6	0.3	0.6	0.4	20.5	0.0	0.0	124.8*
155.3[c]	16.6	6.7	1.0	3.0	3.9	0.0	1.0	38.2	0.0	0.0	48.8*
155.4	16.5	60.3	2.2	2.4	3.0	0.0	2.9	17.4	0.0	0.0	95.5*
157.0[c]	16.1	76.1	0.8	2.4	0.8	0.3	0.3	10.8	0.0	0.0	118.7
157.1[c]	16.5	3.2	4.1	0.6	1.6	0.0	0.8	33.3	0.0	0.0	46.4*
157.3	16.1	109.5	1.9	11.2	1.1	0.0	2.0	19.4	0.4	0.3	265.0*
						Upper Farfield					
166.6	16.1	170.8	7.7	44.9	3.2	0.3	1.1	7.8	0.3	0.3	310.1*
176.0	16.2	33.5	7.6	0.0	1.4	0.9	5.3	4.5	0.2	0.4	65.2*
187.1	15.1	3.8	9.1	0.0	2.4	1.2	4.6	0.6	0.3	0.9	29.2*

NOTE: RIVIC18 was used to compute the data presented in this table.
TTEST85 was used to compare density differences between transects.

[a] Gizzard and/or threadfin shad.
[b] Totals include taxa shown plus taxa not shown.
[c] Intake canals.
* Density values separated by asterisks are significantly different from each other at $p \leq 0.0022$.

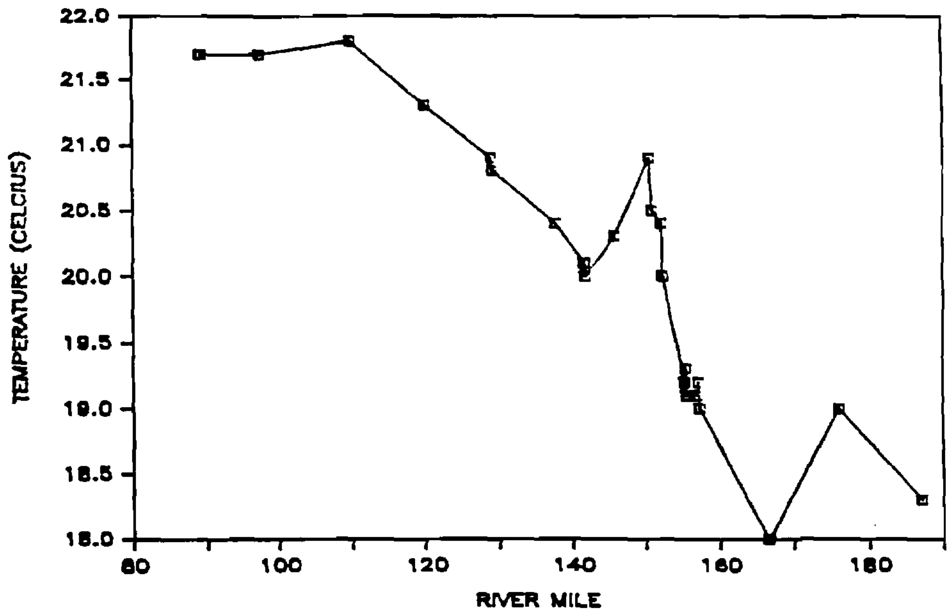
creased from a mean of 12.5° during March to 17.1°C during April. Mean water temperature at each transect was not significantly correlated with mean ichthyoplankton density during April ($r = 0.24$, not significant at $p \leq 0.05$), suggesting that temperatures were appropriate for spawning throughout the study area. Mean density was highest in the lower farfield (193.6/1000 m^3), intermediate in the nearfield (150.7/100 m^3), and lowest in the upper farfield 134.5/100 m^3; (Table 3-20). All differences were significant at $p \leq 0.05$ (Table 3-20). The relatively high densities observed in the nearfield and lower farfield were related to the presence of large numbers of American shad eggs. Excluding the intake canals (RM 155.3 and 157.1), American shad density accounted for 41 - 77% of the total ichthyoplankton density at the transects in the nearfield and lower farfield.

Statistical testing indicated significant differences in density between the following pairs of transects during April: RM 89.3 - 97.5, 141.5 - 141.7, 155.2 - 155.3, 155.3 - 155.4, 157.1 - 157.3, 166.6 - 176.0, and 176.0 - 187.1 (Table 3-22). All of these differences were due to large changes in American shad density between transects and are the result of localized American shad spawning. The only exception is the differences between the intake canals (RM 155.3 and 157.1) and the neighboring river transects (RM 155.2, 155.4, and 157.3), where differences may be due both to a lack of spawning in the canals and to the settling of American shad eggs to the canal bottoms.

Ichthyplankton densities declined slightly during May, averaging 139.4 organisms/1000 m^3 (excluding the intake canals), compared with 156.6/1000 m^3 during April (Figure 3-10; Table 3-23). Mean temperature averaged 20.1°C during May, compared with 17.1°C during April. Densities averaged 297.4/1000 m^3 in the upper farfield, 119.6/1000 m^3 in the nearfield, and 90.4/1000 m^3 in the lower farfield (Table 3-20).

Mean temperature and mean density at each transect (excluding the intake canals) were significantly ($p \leq 0.05$) correlated during May ($r = -0.77$). The negative correlation probably occurred because spawning activity was beginning to subside in the lower farfield had exceeded optimal spawning temperatures by May. American shad was the dominant taxon in the lower farfield and nearfield during May, whereas American shad and gizzard and/or threadfin shad (i.e., other shad) were the dominant taxa in the upper farfield.

Statistical testing indicated significant differences in density between the following pairs of transects during May: RM 155.3 - 155.4, 157.0 - 157.1, 157.1 - 157.3, 157.3 - 166.6, and 166.6 - 176.0. As in the previous months, the statistically significant differences between RM 155.3 - 155.4, 157.0 - 157.1 and 157.1 - 157.3 were due to low American shad densities in the intake canals. The statistically significant density difference between RM 157.3 and 166.6 was due to high densities of American shad (mean of 143.3/1000 m^3) and other shad (primarily gizzard and threadfin shad, 83.5/1000 m^3) at RM 166.6. The statistically significant difference between RM 166.6 and 176.0 was due to much



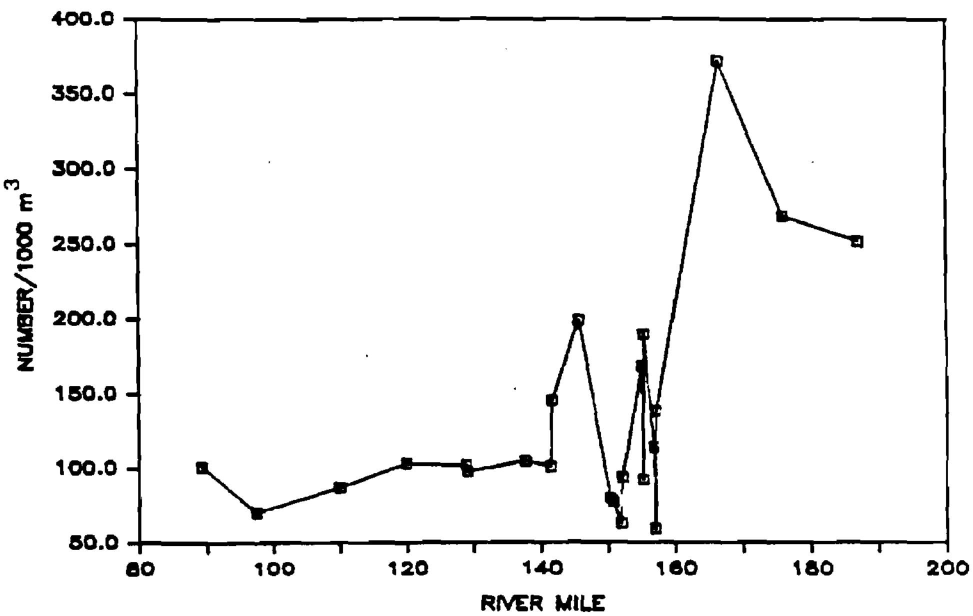


Figure 3-10. Mean ichthyoplankton density (no./1000 m^3) and mean temperature (°C) at Savannah River transects during May (RIVIC18). February - July 1985.

Table 3-23. Mean ichthyoplankton densities (no./1000 m^3) and temperatures (°C) at Savannah River transects during May 1985.

River Mile	Temp (°C)	American shad	blue-back herring	striped bass	other shad[a]	unid. Clupeidae	minnows (Cyprinidae)	spotted suckers	sunfish	crappie	Total ichthyo-plankton[b]
					Lower Farfield						
89.3	21.7	67.9	0.6	5.6	5.2	2.7	4.1	6.2	4.2	0.0	101.2
97.5	21.7	39.6	4.3	0.6	11.2	2.2	5.2	2.5	0.3	0.0	70.2
110.0	21.8	55.7	0.8	0.3	4.9	2.5	9.8	4.2	0.7	0.0	87.2
120.0	21.3	68.1	1.7	0.3	7.2	3.9	6.8	7.0	0.9	0.3	103.0
					Nearfield						
128.9	20.9	64.8	6.6	0.4	9.1	1.4	6.9	6.6	0.0	0.0	101.7
129.1	20.8	63.5	1.1	0.0	10.9	2.6	4.9	6.3	0.0	0.0	97.6
137.7	20.4	62.7	0.7	0.4	12.2	3.9	3.2	7.6	1.9	0.4	104.6
141.5	20.1	51.7	1.0	0.0	13.6	5.8	3.8	7.6	0.8	0.0	101.2
141.7	20.0	90.7	1.3	0.0	16.1	2.9	2.1	13.0	2.1	0.0	145.2
145.7	20.3	134.4	1.0	0.0	12.6	6.3	5.1	18.6	4.0	0.0	199.0
150.4	20.9	35.1	2.7	0.0	10.5	4.3	2.2	8.3	0.0	1.1	79.8
150.8	20.5	20.9	3.4	0.0	16.0	3.0	4.1	16.5	0.0	0.0	77.7
152.0	20.4	18.5	3.1	0.0	13.5	2.5	4.7	11.5	0.3	0.0	62.7
152.2	20.0	17.2	4.7	10.2	18.0	3.7	10.3	14.6	0.0	0.0	93.9
155.2	19.2	30.7	1.9	69.5	15.7	6.7	5.9	10.3	0.0	0.9	168.2
155.3[c]	19.3	0.4	0.0	12.2	21.5	12.0	3.3	22.5	0.0	0.7	92.2*
155.4	19.1	34.1	1.1	85.5	22.9	9.4	5.6	12.7	0.0	0.3	189.9
157.0	19.1	46.9	0.7	0.0	12.8	4.2	8.5	15.3	0.0	0.7	114.3*
157.1[c]	19.2	1.2	0.0	0.0	13.5	7.4	1.9	22.3	0.0	0.0	59.0*
157.3	19.0	62.1	0.7	0.0	19.2	1.0	6.3	19.4	0.0	0.0	138.2*
					Upper Farfield						
166.6	18.0	143.3	2.8	13.7	83.5	12.6	13.4	15.0	0.3	0.4	371.7*
176.0	19.0	29.7	1.2	0.4	156.0	15.8	19.8	5.9	0.7	1.1	268.5
187.1	18.3	10.4	2.1	0.0	126.6	11.6	17.7	1.9	0.8	1.1	251.9

NOTE: RIVIC18 was used to calculate the data presented in this table.
TTEST85 was used to compare density differences between transects.

[a] Gizzard and/or threadfin shad.
[b] Totals include taxa shown plus taxa not shown.
[c] Intake canals.
* Density values separated by asterisks are significantly different from each other at $p \leq 0.0022$.

lower American shad densities (mean of 29.7/1000 m^3) at RM 176.0 than at RM 166.6 (mean of 143.3/1000 m^3).

Spawning activity declined in June, with mean densities ranging from 196.8 organisms/1000 m^3 at RM 166.6 to 6.5/1000 m^3 at RM 110.0 (Figure 3-11; Table 3-24). Densities averaged 122.0/1000 m^3 in the upper farfield, 34.8/1000 m^3 in the nearfield, and 11.7/1000 m^3 in the lower farfield (Table 3-24). Densities were significantly greater in the upper farfield than in the nearfield and significantly greater in the nearfield than in the lower farfield, indicating that spawning was ending in the lower river but continuing in the upper river. This phenomenon was also observed during June 1983 and 1984 (Paller et al. 1984, 1985). River temperatures averaged 23.1°C during June. The correlation between mean temperature and mean density at each transect was significant and negative ($r = -0.65$; $p \leq 0.05$), indicating more spawning at the cooler transects in the upper farfield than elsewhere in the river.

Statistical testing indicated significant differences in density between the following transect pairs during June: RM 120.0 - 128.9, 157.1 - 157.3, and 157.3 - 166.6. The relatively high mean density at RM 128.9 (29.8/1000 m^3), compared with RM 120.0 (7.2/1000 m^3), was due to higher densities of striped bass and American shad at RM 128.9. The high density at RM 166.6 (196.8/1000 m^3), compared with RM 157.3 (40.0/1000 m^3), was

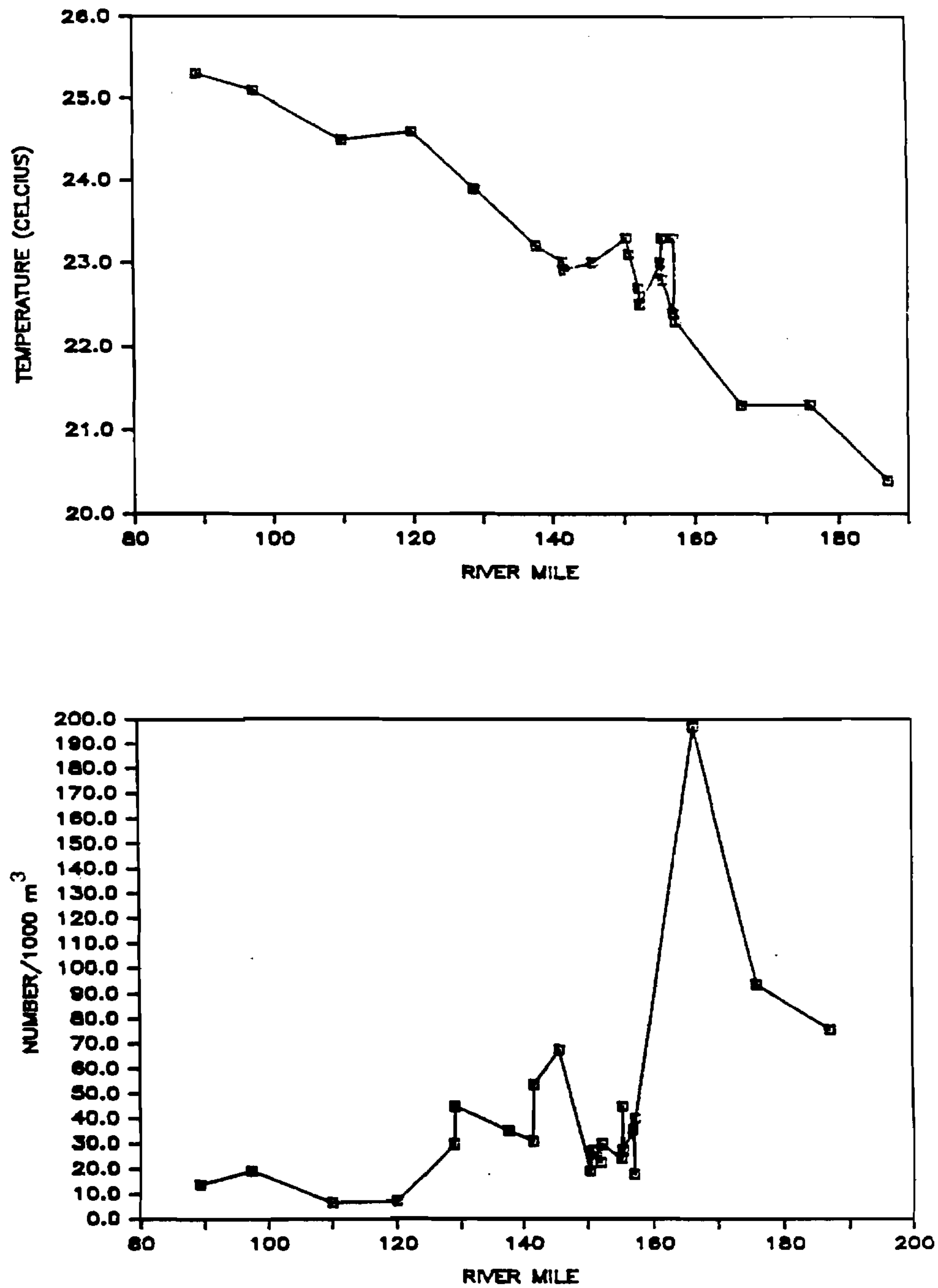


Figure 3-11. Mean ichthyoplankton density (no./1000 m^3) and mean temperature (°C) at Savannah River transects during June (RIVIC18). February - July 1985.

Table 3-24. Mean ichthyoplankton densities (no./1000 m^3) and temperatures (°C) at Savannah River transects during June 1985.

River Mile	Temp (°C)	American shad	blue-back herring	striped bass	other shad[a]	unid. Clupeidae	minnows (Cyprinidae)	spotted suckers	sunfish	crappie	Total ichthyo-plankton[b]
					Lower Farfield						
89.3	25.3	2.4	0.0	0.0	5.3	0.5	0.0	0.0	1.3	0.0	13.8
97.5	25.1	1.8	0.0	0.7	13.8	0.0	0.3	0.0	0.0	0.0	19.3
110.0	24.5	3.2	0.0	0.0	1.5	0.0	0.0	0.8	0.0	0.0	6.5
120.0	24.6	1.6	0.0	0.0	1.5	0.3	0.4	0.4	1.2	0.0	7.2*
					Nearfield						
128.9	23.9	5.6	0.0	11.6	3.6	0.0	0.7	1.1	1.4	0.4	29.8
129.1	23.9	12.8	1.7	23.2	1.2	0.0	0.4	0.8	0.7	0.0	44.8
137.7	23.2	15.1	1.2	0.4	5.7	6.3	0.8	0.8	1.4	0.0	35.1
141.5	23.0	10.4	1.7	0.0	7.5	3.2	0.9	2.0	2.3	0.0	30.8
141.7	22.9	26.3	1.7	0.0	4.4	6.5	0.2	0.4	5.4	0.0	53.4
145.7	23.0	48.5	0.4	0.0	5.7	1.2	1.9	1.7	1.0	0.9	67.4
150.4	23.3	8.7	0.7	0.0	2.5	1.8	1.0	0.7	0.0	0.0	19.1
150.8	23.1	7.6	4.7	0.0	1.8	0.7	1.5	4.4	0.4	0.0	27.1
152.0	22.7	3.3	3.1	0.0	3.6	4.6	2.5	1.8	0.0	0.0	22.7
152.2	22.5	4.5	5.2	0.0	4.4	4.1	1.3	2.2	0.0	0.0	29.8
155.2	23.0	6.7	0.9	0.0	3.9	2.3	0.3	1.5	0.0	0.0	24.3
155.3[c]	23.3	0.6	4.4	0.0	19.0	9.7	1.8	5.7	0.0	0.0	44.9
155.4	22.8	7.9	0.7	0.0	4.3	2.0	0.8	2.0	0.5	0.0	27.3
157.0	22.4	11.0	0.6	0.3	10.9	2.3	2.0	1.6	1.2	0.0	35.4
157.1[c]	23.3	0.0	1.8	0.0	4.0	4.1	1.1	3.9	0.7	0.0	17.9*
157.3	22.3	19.4	0.3	0.0	4.2	2.8	1.5	2.0	0.0	0.0	40.0*
					Upper Farfield						
166.6	21.3	27.7	8.2	0.0	57.2	53.8	0.7	1.2	0.4	0.0	196.8
176.0	21.3	22.7	4.0	0.0	18.8	16.4	2.8	1.6	1.0	0.0	93.7
187.1	20.4	5.4	4.4	0.5	17.7	10.3	8.2	0.7	1.2	0.0	75.6

NOTE: RIVIC18 was used to compute the data presented in this table.
TTEST85 was used to compare density differences between transects.

[a]Gizzard and/or threadfin shad.
[b]Totals include taxa shown plus taxa not shown.
[c]Intake canals.
*Density values separated by asterisks are significantly different from each other at $p \leq 0.0022$.

largely due to higher densities of American shad, "other" shad, and unidentified clupeids at RM 166.6 than at 157.3. The low mean density in the 1G intake canal RM 157.1 (17.9/1000 m^3), compared with the neighboring river transect (RM 157.3; 40.0/1000 m^3), was due to a lack of American shad ichthyoplankton in the intake canal.

Spawning activity in the river was low during July, with mean ichthyoplankton densities ranging from 0.0 organisms/1000 m^3 at RM 110.0 and 155.3 to 12.7/1000 m^3 at RM 187.1 (Figure 3-12; Table 3-25). As in June, densities were significantly ($p \leq 0.05$) higher in the upper farfield (mean of 11.1/1000 m^3) than in the nearfield (2.5/1000 m^3) or lower farfield (1.1/1000 m^3; Table 3-20). Mean temperature in the Savannah River was 23.2°C, with the highest temperatures at the downstream end of the study area (mean of 25.1°C at RM 89.3) and lowest temperatures at the upstream end of the study area (mean of 21.5°C at RM 187.1). The correlation between mean temperature and mean density at each transect was significant and negative ($r = -0.67$; $p \leq 0.05$), suggesting that spawning was only occurring in cooler, upriver reaches.

Ichthyoplankton densities over the entire February - July sample period ranged from a mean of 22.2/1000 m^3 in the 1G intake canal (RM 157.1) to a mean of 149.3/1000 m^3 at RM 166.6 (Table 3-26). Densities were significantly higher in the upper farfield (mean of 94.6/1000 m^3) than in the nearfield (mean of

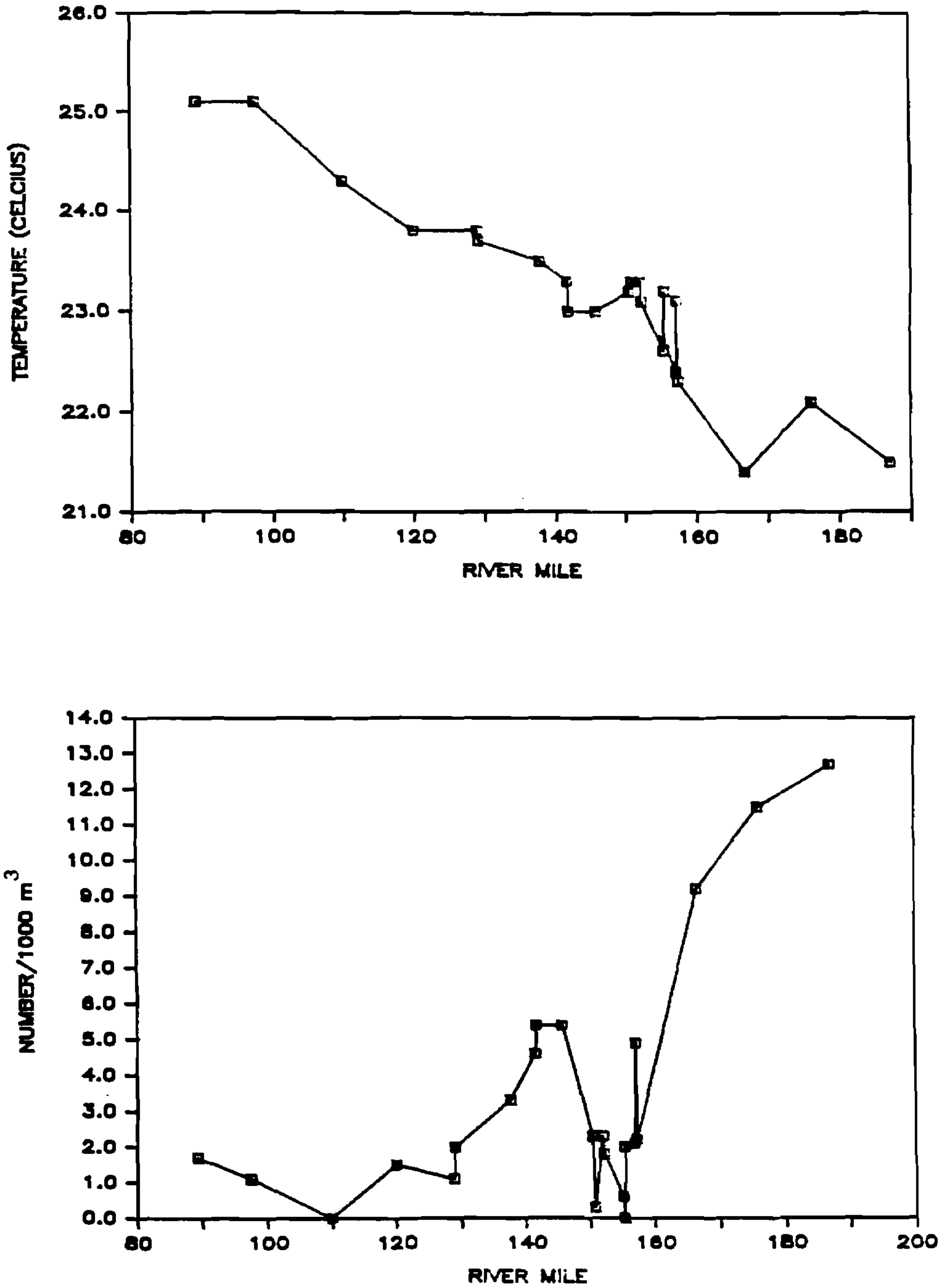


Figure 3-12. Mean ichthyoplankton density (no./1000 m^3) at Savannah River transects during July (RIVIC18). February - July 1985.

Table 3-25. Mean ichthyoplankton densities (no./1000 m^3) and temperatures (°C) at Savannah River transects during July 1985.

River Mile	Temp (°C)	American shad	blue-back herring	striped bass	other shad[a]	unid. Clupeidae	minnows (Cyprinidae)	spotted suckers	sunfish	crappie	Total ichthyo-plank-ton[b]
						Lower Farfield					
89.3	25.1	0.0	0.8	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1.7
97.5	25.1	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.0	0.0	1.1
110.0	24.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
120.0	23.8	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.6	0.0	1.5
						Nearfield					
128.9	23.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.1
129.1	23.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.4	0.0	2.0
137.7	23.5	0.2	0.3	0.0	0.0	0.0	0.3	0.0	0.3	0.0	3.3
141.5	23.3	0.0	0.6	0.0	0.3	0.0	0.3	0.0	0.9	0.0	4.6
141.7	23.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	5.4
145.7	23.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.3	5.4
150.4	23.2	0.7	0.3	0.0	0.0	0.0	0.7	0.0	0.0	0.0	2.3
150.8	23.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3
152.0	23.3	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.3	0.0	2.3
152.2	23.1	0.0	0.5	0.0	0.3	0.0	0.3	0.0	0.3	0.0	1.8
155.2	22.6	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.6
155.3[c]	23.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
155.4	22.7	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.3	0.0	2.0
157.0	22.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1
157.1[c]	23.1	0.0	0.0	0.0	0.0	1.7	0.5	0.0	0.4	0.0	4.9
157.3	22.3	0.0	0.0	0.0	0.0	0.7	0.3	0.0	0.6	0.0	2.2
						Upper Farfield					
166.6	21.4	0.7	0.4	0.0	0.3	0.5	0.8	0.0	0.4	0.0	9.2
176.0	22.1	6.5	0.8	0.0	0.4	1.0	0.0	0.0	0.3	0.0	11.5
187.1	21.5	1.1	0.6	0.0	0.4	1.1	3.6	0.0	0.9	0.0	12.7

NOTE: RIVIC18 was used to compute the data presented in this table.
TTEST85 was used to compare density differences between transects.

[a] Gizzard and/or threadfin shad.
[b] Totals include taxa shown plus taxa not shown.
[c] Intake canals.

Table 3-26. Mean ichthyoplankton densities (no./1000 m^3) and temperatures (°C) at Savannah River transects during February - July 1985.

River Mile	Temp (°C)	American shad	blue-back herring	striped bass	other shad[a]	unid. Clupeidae	minnows (Cyprinidae)	spotted suckers	sunfish	crappie	Total ichthyo-plankton[b]
					Lower Farfield						
89.3	19.0	47.4	0.9	2.0	2.2	1.2	2.5	3.7	1.4	0.1	67.8
97.5	19.0	26.6	1.7	1.2	4.7	1.3	1.6	2.1	0.2	0.1	44.1
110.0	18.9	39.6	0.6	1.5	1.2	0.7	3.2	2.7	0.2	0.1	55.6
120.0	18.5	35.3	0.8	1.3	1.7	2.3	2.2	3.6	0.7	0.4	51.7
					Nearfield						
128.9	18.4	41.7	1.4	5.3	2.2	0.3	4.1	4.2	1.0	0.2	64.2
129.1	18.3	31.3	0.8	6.3	1.9	0.7	2.9	3.5	1.4	0.2	54.7
137.7	18.0	34.1	1.8	0.4	2.9	1.7	1.9	5.4	1.4	0.1	55.2
141.5	17.8	30.0	1.4	0.1	3.4	1.5	1.5	6.4	1.1	0.1	50.9
141.7	17.7	54.6	0.9	0.5	3.7	1.5	1.8	10.6	1.8	0.3	83.2
145.7	18.0	63.2	0.7	0.6	3.0	1.2	1.6	10.0	1.5	0.5	84.3
150.4	18.5	22.0	1.0	2.4	2.1	1.0	0.8	4.1	0.2	0.3	44.7
150.8	18.2	12.6	1.9	0.3	3.0	0.6	1.0	6.2	0.1	0.0	31.8
152.0	18.1	10.6	1.4	3.7	3.2	1.3	1.6	4.6	0.1	0.1	28.7
152.2	17.8	14.2	2.2	3.3	3.6	1.3	2.0	5.9	0.1	0.1	43.1
155.2[c]	17.2	18.2	2.6	16.0	3.1	1.5	1.0	5.8	0.0	0.2	67.1
155.3[c]	17.4	0.3	0.9	2.5	7.0	3.4	1.0	11.7	0.1	0.2	30.7
155.4	17.1	19.3	0.8	13.6	4.8	1.7	1.6	5.7	0.1	0.0	57.0
157.0[c]	16.9	24.6	0.4	0.5	3.8	1.0	1.7	4.7	0.2	0.1	47.5
157.1[c]	17.3	0.8	1.1	0.1	3.0	2.1	0.7	10.4	0.2	0.1	22.2
157.3	16.7	36.0	0.5	2.1	3.8	0.7	1.6	7.0	0.2	0.2	81.6
					Upper Farfield						
166.6	16.6	59.4	3.2	10.7	22.3	10.4	2.5	4.0	0.2	0.1	149.3
176.0	16.6	15.7	2.4	0.1	27.2	5.3	4.5	2.0	0.4	0.2	70.9
187.1	15.9	3.3	2.8	0.1	22.7	3.8	5.4	0.6	0.6	0.4	58.6

NOTE: RIVIC18 was used to compute the data presented in this table.

[a] Gizzard and/or threadfin shad.
[b] Totals include taxa shown plus taxa not shown.
[c] Intake canals.

56.7/1000 m^3) or lower farfield (mean of 54.8/1000 m^3) which were not significantly different from each other ($p \leq 0.05$; Table 3-20).

An examination of the average density at each transect over all dates indicates that densities were lower at RM 150.8 and at RM 152.0 than at the rest of the transects (excluding the intake canals), primarily due to a relative scarcity of American shad ichthyoplankton (Figure 3-13). RM 150.8 and RM 152.0 are upstream from the mouth of Four Mile Creek (RM 150.6), hence not exposed to reactor discharge. Although these stations are downstream from Beaver Dam Creek (RM 152.1), the discharge from this stream was only moderately heated. Thermal-imagery studies in done in August 1982 indicated that Savannah River temperatures directly in front of the mouth of Beaver Dam Creek were only several °C above ambient river temperature (Bristow and Doak 1983), and temperatures measured near the South Carolina bank just downstream from Beaver Dam Creek during the present study (RM 152.0) were, at most, 1°C above ambient (Figure 3-6). It is unlikely that the relatively low average ichthyoplankton densities at RM 150.8 and RM 152.0 are due to SRP impacts.

This analysis of the spatial and temporal distribution of ichthyoplankton in the Savannah River did not indicate that in total ichthyoplankton (i.e., all species combined) abundance decreased below the mouth of Four Mile Creek (RM 150.6). This conclusion contradicts the findings of the horizontal distribution

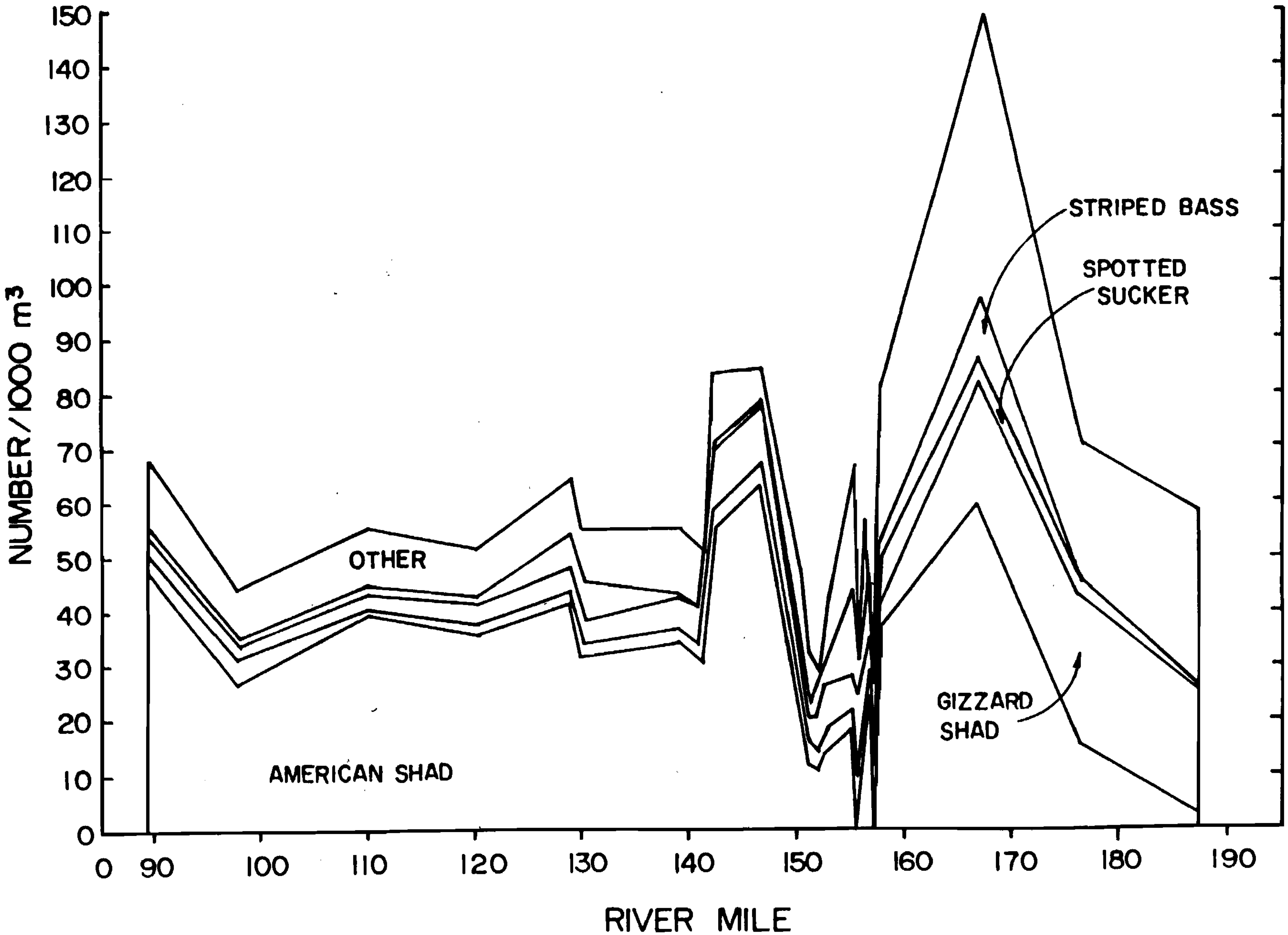


Figure 3-13. Average density of ichthyoplankton taxa at Savannah River transects (RIVIC18). February - July 1985.

analysis, which indicated that larval densities were significantly reduced near the South Carolina bank just below Four Mile Creek (Tables 3-15 and 3-17). This discrepancy occurred because larval densities near the South Carolina bank were treated separately from egg densities and from mid-river and Georgia bank densities in the horizontal distribution analyses, whereas banks and life stages were averaged together in the spatial and temporal distribution analysis. In the latter analysis, the reduction in larval density near the South Carolina bank was of insufficient magnitude to cause a noticeable effect at RM 150.4. Together, the results of the comparatively high-resolution horizontal distribution analysis and the more general spatial and temporal distribution analysis suggest that the density reduction below the mouth of Four Mile Creek was real, but was so localized and species-specific (only spotted sucker larvae were reduced; Table 3-17) that its effect on overall river ichthyoplankton abundance was undetectable.

3.1.3 Oxbow Ichthyoplankton

Five oxbows were sampled during 1984: two in the upper farfield (at RM 167.4 and 183.0), two in the nearfield (at RM 156.7 and 153.2), and one in the lower farfield (at RM 100.2). The average depth of the oxbows (in the area where they were sampled) ranged from 2.0 - 3.6 m (Table 3-27), and all were approximately equal to the river in width or slightly narrower. Although all the oxbows were connected to the river (some at both ends), current velocities in the oxbows during 1985 were usually too low to

Table 3-27. Mean (and range) of chemical and physical parameters in five oxbows on the Savannah River. February - July 1985.

Oxbow River Mile (RM)		Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Conductivity (μS/cm)	Alkalinity (mg/L)	Depth (m)	Number of dates sampled
100.2	Top[a]	21.3 (5.5-30.0)	7.9 (3.6-12.0)	7.0 (4.3-9.6)	92.0 (63.0-118.0)	25.5 (12.5-38.0)	2.8 (2.1-5.2)	26
	Bottom[b]	19.3 (5.5-28.0)	4.3 (0.1- 8.7)	6.4 (4.2-7.5)	94.8 (64.0-144.0)	-[c]		
153.2	Top	19.9 (6.6-30.4)	8.3 (5.9-11.3)	6.8 (5.8-8.5)	84.9 (62.0-108.0)	19.7 (13.8-22.5)	2.7 (1.8-4.6)	26
	Bottom	17.3 (6.6-25.8)	5.4 (0.1- 9.0)	6.6 (5.8-7.8)	97.1 (56.0-187.0)	-		
156.7	Top	17.8 (6.9-26.6)	6.4 (2.8- 9.9)	6.3 (5.3-7.1)	81.8 (49.0-112.0)	19.0 (11.3-25.1)	2.1 (1.5-3.0)	26
	Bottom	12.1 (6.9-19.5)	6.4 (3.1- 9.5)	6.1 (4.2-7.0)	79.2 (41.0-122.0)	-		
167.4	Top	18.8 (6.7-31.2)	8.8 (4.9-12.2)	6.7 (4.9-8.3)	84.3 (53.0-120.0)	19.0 (11.8-21.8)	3.6 (2.1-6.4)	26
	Bottom	16.7 (6.7-28.3)	7.7 (4.0-15.7)	6.6 (5.0-8.8)	81.7 (51.0-106.0)	-		
183.0	Top	21.8 (6.8-33.1)	8.9 (4.5-19.7)	6.6 (5.1-9.3)	49.7 (39.0- 70.0)	14.6 (9.3-50.0)	2.0 (1.5-4.0)	26
	Bottom	18.8 (6.8-27.8)	5.3 (0.8- 8.6)	6.2 (4.9-7.8)	51.6 (34.0- 72.0)	-		

NOTE: RIVIC7 was used to compute the data presented in this table.

[a] Top samples taken approximately 1 m below the surface.
[b] Bottom samples taken approximately 1 m above the bottom.
[c] Samples not taken.

measure (< 0.1 m/s). In 1984, in contrast, mean current velocities in the oxbows ranged between 2.5 and 13.4 m/s (Paller et al. 1985). In 1984, Savannah River levels were higher than in 1985, resulting in greater water exchange between the oxbows and the river.

Chemical and physical parameters in the oxbows were in most respects similar to those in the river (Table 3-27 and 3-28). Exceptions were current velocity, which was much lower (generally too low to measure in the oxbows vs. 71.3 cm/s in the river), and depth, which was slightly less (mean of 2.6 m in the oxbows vs. 3.3 m in the river). Unlike the river, some of the more slowly flowing oxbows tended to stratify in the summer. The average near-top temperature (19.9°C) was approximately 3.0°C higher than the average near-bottom temperature (16.8°C) in the oxbows. Oxygen concentration, too, was higher near the top (mean of 8.1 mg/L) than the bottom (mean of 5.8 mg/L) in the oxbows. Stratification is generally associated with standing or slow-flowing waters (Wetzel 1983) and was not observed in the more rapidly flowing and turbulent Savannah River (Table 3-28).

A total of 10,214 larvae and 108 eggs were collected from the five oxbows sampled during 1985 (Table 3-29). Species composition was dominated by gizzard and/or threadfin shad (47.4%) and unidentified Clupeidae (14.9%; Table 3-6). It is probable that most of the unidentified clupeids were gizzard and/or threadfin shad at developmental stages where definitive identifications were not practical. Other dominant taxa in the oxbows were the sun-

Table 3-28. Mean (and range) of chemical and physical parameters of the mid- and lower reaches of the Savannah River. Weekly samples were taken at 21 transects between RM 89.3 and 187.1. February - July 1985.

River Depth		Parameters: Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)	Alkalinity (mg/L)	Current (cm/s)	Depth (m)
Top[a]	Mean	17.8	7.1	6.5	83.4	18.3	76.6	3.3
	(Range)	(5.6-26.5)	(2.2-13.6)	(4.0-8.4)	(38.0-179.0)	(4.0-38.0)	(20.0-160.0)	(0.9 - 8.8)
	S.D.	5.5	1.3	0.7	14.1	2.8	16.7	1.2
Bottom[b]	Mean	17.8	7.0	6.5	83.0	19.5	66.1	
	(Range)	(5.6-26.5)	(2.0-13.5)	(4.1-8.4)	(38.0-126.0)	(16.3-21.0)	(16.0-140.0)	
	S.D.	5.5	1.2	0.7	14.3	2.0	15.5	

NOTE: RIVIC7 was used to calculate the data presented in this table.

[a]Approximately 1 m below the surface.
[b]Approximately 1 m above the bottom.

Table 3-29. Numbers of ichthyoplankton collected and average ichthyoplankton densities in Savannah River oxbows. February - July 1985.

Oxbow location (RM)	Number larvae	Number eggs	Number taxa[a]	Mean ichthyoplankton density (no./1000 m^3)	Density range	Density coefficient of variation (%)
100.2	7711	0	8	1556.2	0.0 - 17190.5	189.7
153.2	185	10	10	38.6	0.0 - 352.4	168.7
156.7	148	1	6	57.2	0.0 - 469.3	205.4
167.4	1760	40	9	289.7	0.0 - 3837.4	276.1
183.0	410	57	11	108.1	0.0 - 791.1	141.4
Total	10,214	108				

NOTE: RIVIC18 was used to compute the data presented in this table.

fishes (20.7% of all ichthyoplankton collected) and the blueback herring (6.2%). While these taxa apparently spawned in the oxbows, others made little use of them, most notably striped bass (mean of 0.2 individuals/1000 m^3 in the oxbows, compared with 3.3/1000 m^3 in the river; Table 3-6) and American shad (3.4/1000 m^3 in the oxbows, compared with 30.5/1000 m^3 in the river; Table 3-6).

Ichthyoplankton density varied between oxbows and was particularly high in the oxbow at RM 100.2. Average density in the oxbow at RM 100.2 was 1556.2 ichthyoplankton/1000 m^3, compared with 38.6 - 289.7/1000 m^3 in the other oxbows (Table 3-29). The density difference between the oxbow at RM 100.2 and the other oxbows was consistent across all dates and not due solely to a few extremely high peaks (Figure 3-14). Except for the fact that spawning began about two weeks earlier in the oxbow at RM 100.2 than in the other oxbows (possibly due to slightly elevated temperatures), seasonal trends in the oxbow at RM 100.2 were similar to those in the other oxbows and the river. In addition, taxonomic composition was similar between the oxbows, indicating that the high densities in the oxbow at RM 100.2 were not due to an unusual level of spawning by a single species (Table 3-30). The occurrence of extremely high densities in the oxbow at RM 100.2 was also observed during 1983. Reasons for the apparent productivity of the oxbow at RM 100.2 are unknown at present.

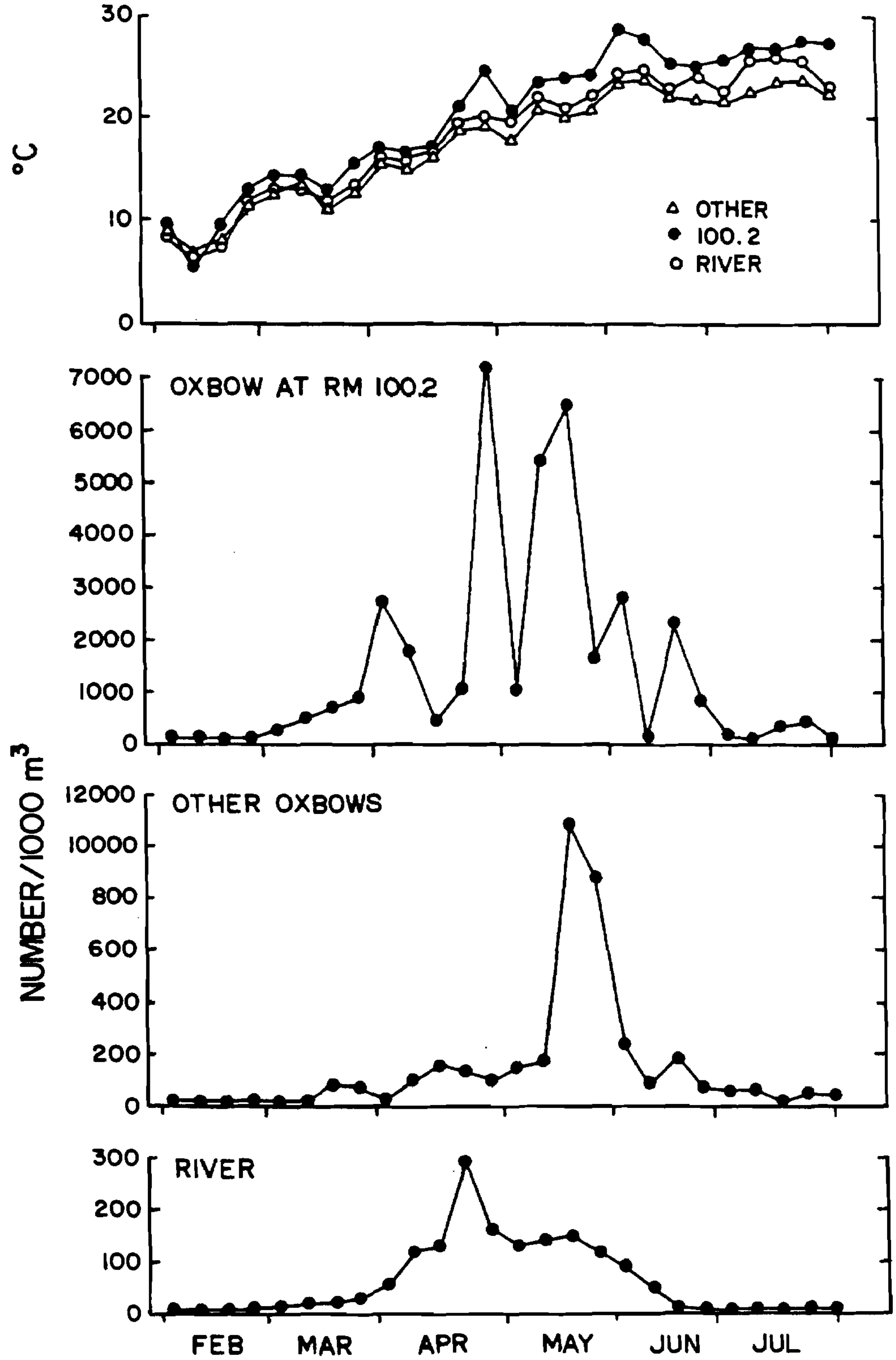


Figure 3-14. Mean ichthyoplankton density (no./1000 m^3) and temperatures (°C) in oxbow at RM 100.2, the other oxbows and the Savannah River (RIVIC13). February - July 1985.

Table 3-30. Percent abundance of ichthyoplankton in Savannah River oxbows. February - July 1985.

Taxa	Oxbows (RM) 100.2	153.2	156.7	167.4	183.0
unid. Clupeidae	10.3	26.2	22.1	35.6	3.4
blueback herring	5.6	12.8	9.4	8.1	5.4
American shad	0.1	2.1	43.6	-	0.2
gizzard and/or threadfin shad	48.4	35.4	10.7	53.9	21.6
minnow (Cyprinidae)	0.0	0.0	0.7	0.1	0.2
carp	0.0	0.5	0.0	0.1	0.2
spotted sucker	0.0	1.5	0.0	0.1	0.0
topminnow	0.0	0.0	0.0	0.1	0.0
mosquitofish	0.0	0.0	0.0	0.0	0.9
brook silverside	0.1	0.0	0.0	0.1	1.7
striped bass	0.0	3.1	0.0	0.0	0.0
unid. sunfish	1.6	1.0	5.4	0.0	10.9
sunfish (*Lepomis* spp.)	23.2	0.5	4.7	0.1	31.3
crappie	3.2	3.1	1.3	0.0	7.3
darter	2.5	10.8	0.0	0.1	8.4
yellow perch	4.5	1.5	0.0	0.0	5.1
unid. larvae	0.6	1.0	1.3	0.3	3.4
other eggs	0.0	0.5	0.7	1.6	0.0
Total percent	100.1	100.0	99.9	100.2	100.0
Total ichthyoplankton	7711	195	149	1800	467
Number of sampling dates	26	26	26	26	26

NOTE: RIVIC10 was used to compute the data presented in this table.

In addition to being important spawning areas, some oxbows may function as nurseries where larvae can remain until they become less-vulnerable juveniles. Characteristics of the oxbows that might contribute to the survival and growth of larvae to juvenile size are reduced current (hence reduced probability of transport to unfavorable areas) and possibly greater amounts of forage in the form of zooplankton. The importance of backwater areas as nursery zones has been noted by Hergenrader et al. (1982) and Holland and Huston (1984, 1985).

3.1.4 Spatial and Temporal Distribution of Selected Ichthyoplankton Taxa

3.1.4.1 American shad

American shad support a sport and commercial fishery in the Savannah River during their spring spawning migrations. Adult fish spawn at varying distances upstream of the brackish-water zone and have been captured at least as far upstream as the Augusta Diversion Dam (Osteen et al. 1984). The eggs are transported downstream with the current until they hatch or sink to the bottom. Larval shad grow to juvenile size in the river and generally migrate to the sea in the fall of the year they were spawned (Leggett 1976).

Eleven thousand four hundred and ninety four (11,494) American shad eggs and 361 American shad larvae were collected from the study area during 1985 (Table 3-1). This is considerably more than were collected during 1984 (196 larvae and 2520 eggs; Paller et al. 1985) or 1983 (653 larvae and 3612 eggs; Paller et al. 1984), in spite of the fact that sampling effort was reduced during 1985. American shad were abundant enough during 1985 to make them the dominant taxa in the river ichthyoplankton assemblage (50.7% of all ichthyoplankton collected; Table 3-6) and responsible for many of the major spatial and temporal trends in total ichthyoplankton abundance observed during 1985 (Section 3.1.2.5). The abundance of American shad ichthyoplankton (primarily eggs) during 1985 may be due to greater egg survival or to the migration of more spawning adults into the study area during spring 1985 than during previous years of the study. Greater concentration of eggs into a more limited area due to reduced river discharge during 1985 (Figure 3-15) may also be a contributing factor, although unlikely to account for more than a relatively small percentage of the several-fold increase in American shad ichthyoplankton abundance between 1985 and earlier years.

American shad ichthyoplankton were first collected in February at temperatures as low as 10°C (Table 3-19). Densities increased in later months, peaking in April and May at temperatures of 16 - 22°C (Figure 3-16; Tables 3-22 and 3-23). American shad ichthyoplankton were largely absent from the study area by July (Table 3-25). Very few shad were collected at temperatures above 26°C.

The total number of American shad ichthyoplankton transported through the river over the entire study period ranged from an

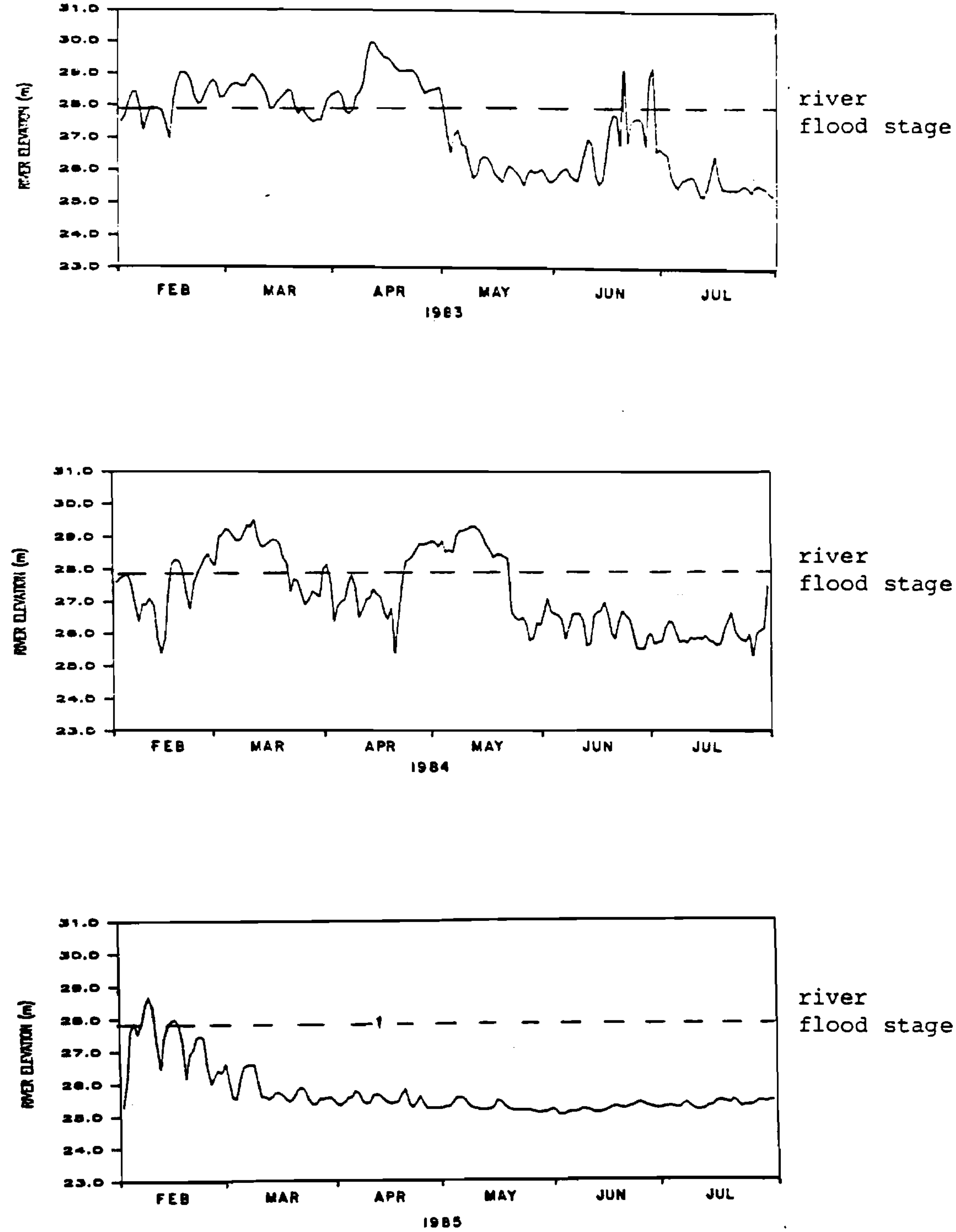


Figure 3-15. Savannah River water levels during the ichthyoplankton sampling programs (February - July) of 1983, 1984, and 1985.

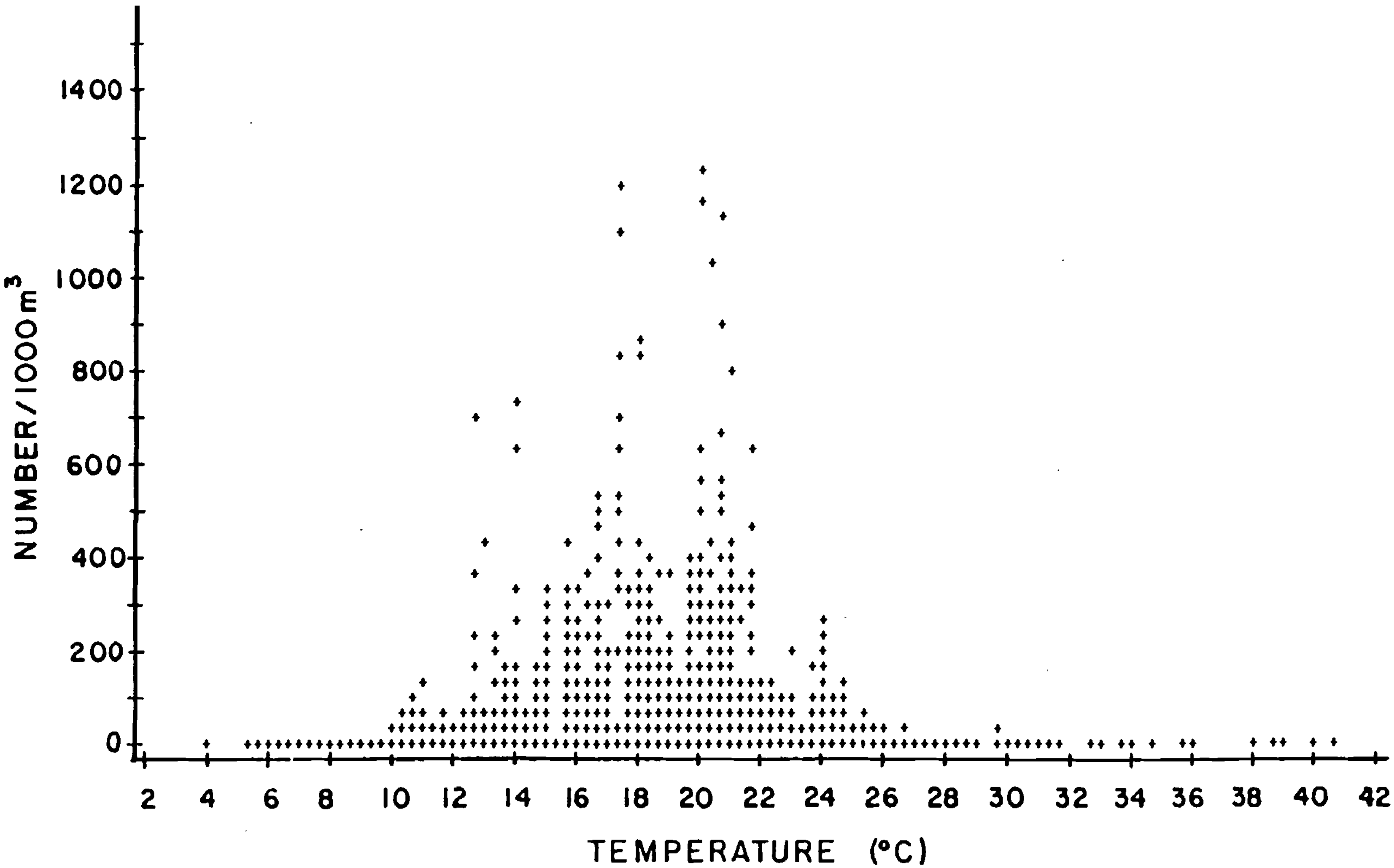


Figure 3-16. Density of American shad ichthyoplankton (no./1000 m^3) collected at different temperatures (°C) in the Savannah River study area. (RIVICMXT and RIVICDT). February - July 1985.

estimated 160 million at RM 145.7 and nearly 160 million at RM 166.6 to 8 million at RM 187.1 (Figure 3-17). The peaks at RM 145.7 and 166.6 probably reflect localized concentrations of spawning fish. Average transport over all river sample stations was 80 million, approximately 28 times higher than the average transport during 1984. Most American shad spawning occurred in the river. With the exception of Steel Creek, transport from the creeks was minimal (Tables 3-9, 3-10, and 3-11). Steel Creek transported approximately 1.6 million American shad larvae and eggs (primarily eggs) into the Savannah River (Table 3-31). As in earlier years, American shad spawning occurred in the vicinity of the SRP, but also in other portions of the river.

3.1.4.2 Striped Bass

Adult striped bass are most abundant in coastal areas but often are found in freshwater, particularly during winter and spring. Upriver spawning migrations along the East Coast generally occur between winter and midsummer (Merriman 1950). Eggs and larvae drift downstream to nursery areas, which are generally in estuaries and the lower portions of rivers. Some current is important in striped bass spawning areas, since egg survival is dependent upon sufficient current to keep them suspended in the water column (Stevens 1967; Bayless 1968).

Striped bass ichthyoplankton were first observed in low numbers in March (Table 3-21). Densities peaked in April and May, declined during June, and were zero by July (Tables 3-22 through

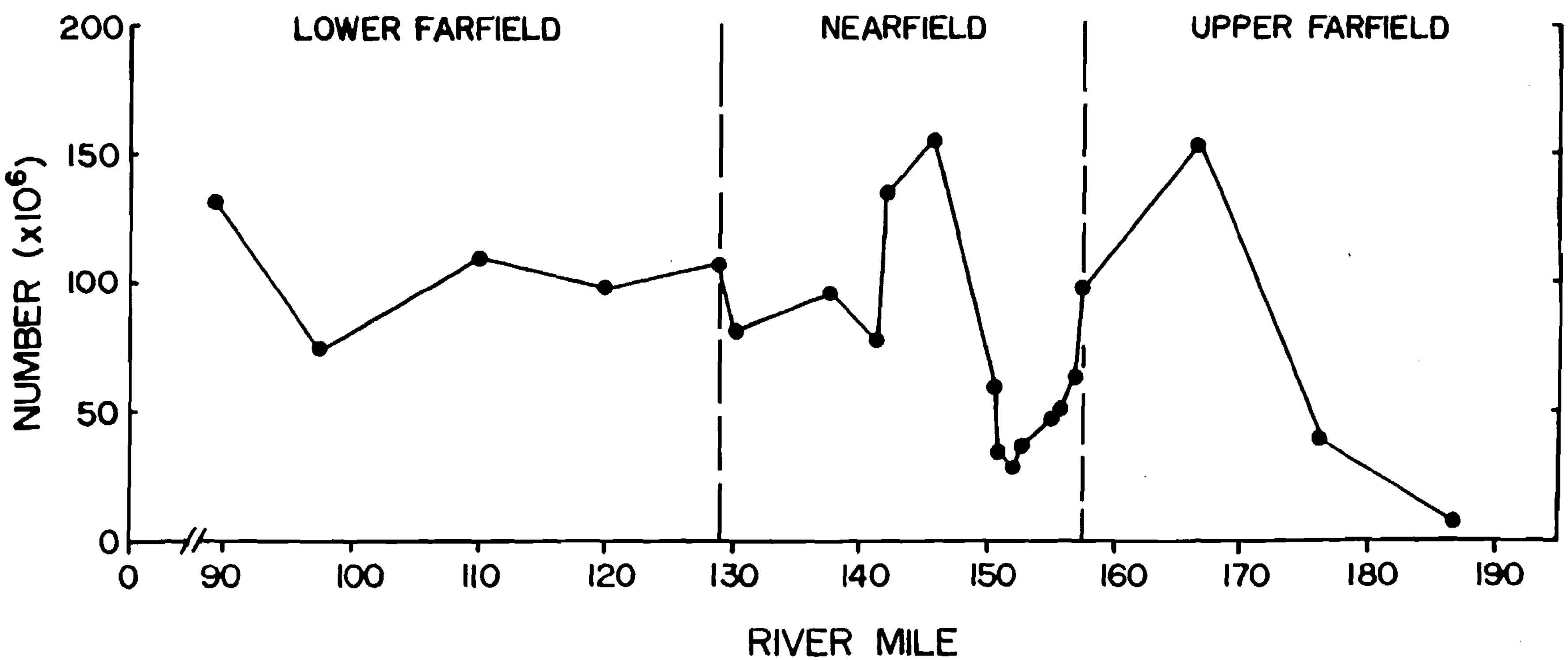


Figure 3-17. Number of American shad ichthyoplankton transported through Savannah River sampling transects (RNTRAN-X). February - July 1985.

Table 3-31. Total number of ichthyoplankton (x 10^3) transported from the mouths of selected Savannah River tributaries. February - July 1985.

Creek (RM)	American shad	blueback herring	striped bass
Buck (92.6)	0	0	0
Briar (97.6)	90	229	71
The Gaul (109.0)	0	0	0
Smith Lake (126.5)	0	0	0
Lower Three Runs (129.0)	0	39	0
Sweetwater (133.5)	0	0	0
Steel (141.6)	1623	1340	0
Four Mile (150.6)	0	15	0
Beaver Dam (152.1)	12	567	0
Upper Three Runs (157.2)	62	201	0
Upper Boggy Gut (162.2)	0	0	0
McBean (164.2)	59	137	0
Hollow (176.1)	61	272	0
Spirit (183.3)	0	60	0

NOTE: CRKPORT was used to compute the data presented in this table.

3-25). The greatest striped bass ichthyoplankton densities were associated with river temperatures of 17 - 25°C (Figure 3-18). These temperatures are comparable to striped bass spawning temperatures reported by other researchers (Merriman 1950). Striped bass spawning began earlier and lasted somewhat longer during 1985 than during 1983 or 1984 (when it was largely confined to May; Paller et al. 1984, 1985).

Striped bass transport exhibited three peaks, suggesting localized aggregations of spawning fish. The peaks occurred at RM 166.6 (28 million larvae and eggs, RM 155.4 (39 million larvae and eggs), and RM 129.0 (16 million larvae and eggs; Figure 3-19). The transport increase that contributed to the peak at RM 155.4 actually began at RM 152.2, indicating considerable striped bass spawning just above and below the 3G intake canal at RM 155.3. In 1984, striped bass transport peaked at RM 141.7, and in 1983, striped bass transport peaked at RM 120.0 and 152.2. Very few striped bass larvae or eggs were collected from the tributary creeks during 1985, which indicates their relative unimportance as striped bass spawning areas (Tables 3-9, 3-10, 3-11, and 3-31).

The collection of striped bass ichthyoplankton at and above RM 141.7 contrasts with the findings of earlier researchers. McFarlane et al. (1978) found neither striped bass larvae nor eggs in ichthyoplankton collections from the vicinity of the intake canals (RM 155.3 and 157.1). Dudley et al. (1977) studied the movements of striped bass tagged with ultrasonic and radio

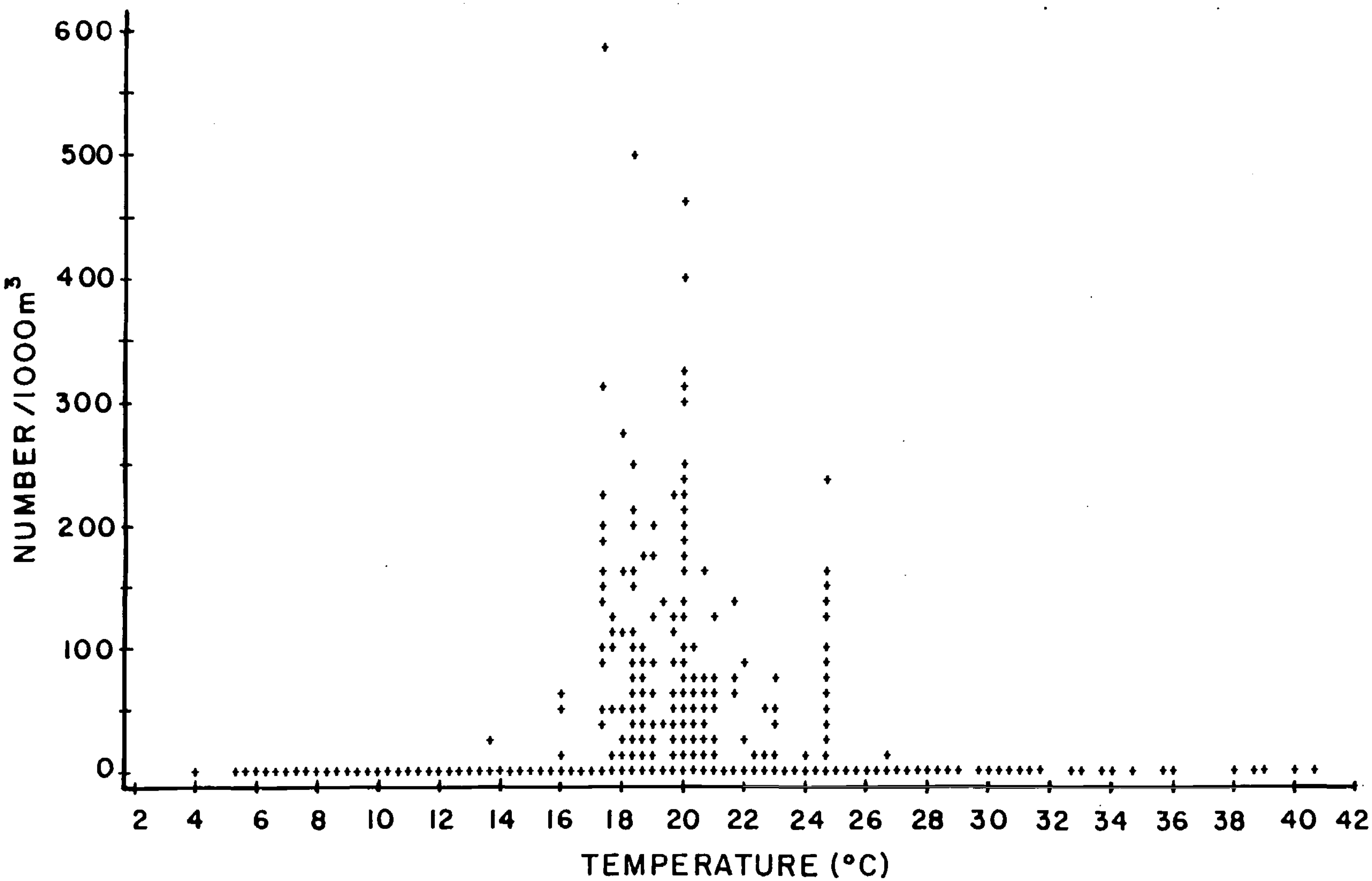


Figure 3-18. Density of striped bass ichthyoplankton (no./1000 m^3) collected at different temperatures (^oC) in the Savannah River study area. (RIVICMXT and RIVICDT). February - July 1985.

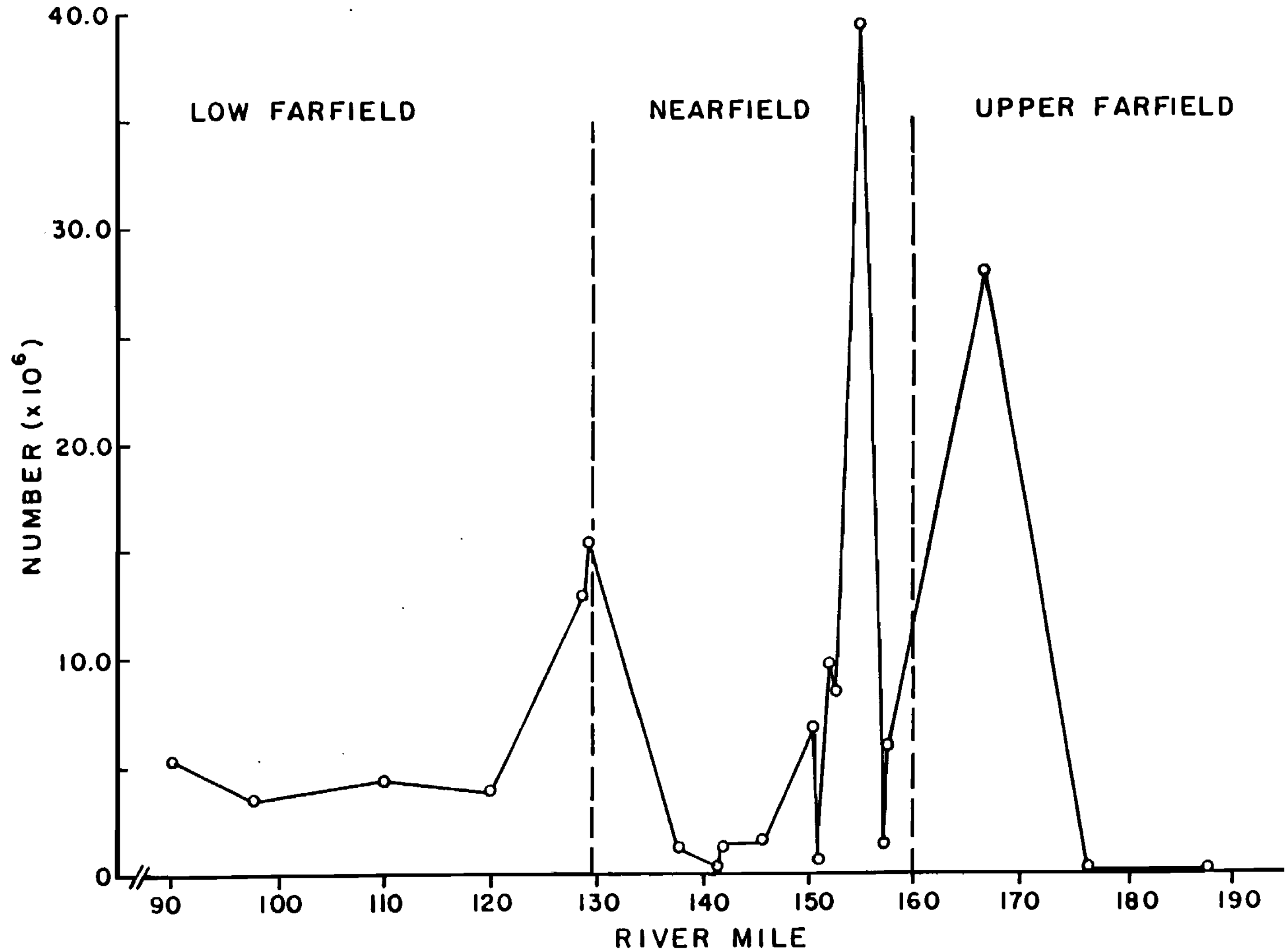


Figure 3-19. Number of striped bass ichthyoplankton transported through Savannah River sampling transects (RNTRAN-X). February - July 1985.

transmitters and suggested that spawning fishes congregated in the lower portion of the Savannah River (approximately RM 18 - 19). These differences may be due in part to methodological differences. McFarlane used 760 μ mesh nets, which may have extruded striped bass ichthyoplankton, rather than the 505 μ mesh nets used in this study (see Paller et al. 1984 for a comparison between 505 μ and 760 μ mesh nets). It is also possible that there are different striped bass populations in the river, one which spawns in the lower portion of the study area and one which spawns farther upstream. This latter possibility was indicated by Dudley et al. (1977), who suggested that the Savannah River may possess a riverine population whose anadromy is greatly reduced in relation to coastal populations.

3.1.4.3 Blueback herring

Blueback herring support bait, food, and commercial fisheries in east coast rivers during their spawning migrations (Curtis 1981). Adults move from coastal waters into brackish and freshwater, where they deposit mildly adhesive eggs in swamps, creeks, and floodlands (Adams and Street 1969; Frankensteen 1976). Juveniles generally migrate downstream when they are approximately 50 mm in total length (Jones et al. 1978).

Blueback herring ichthyoplankton were first observed in the study area during March, peaked in abundance during April and May, declined in abundance during June, and were present in very small numbers during July (Tables 3-21 through 3-25). Spawning largely occurred at temperatures between 13°C and 27°C, with maximum activity between 14°C and 24°C (Figure 3-20). This temperature range is somewhat broader and higher than in 1984, when maximum spawning occurred between 14 and 18°C.

Blueback herring transport averaged approximately 2.6 million in the lower farfield, approximately 3.2 million in the nearfield, and approximately 7.1 million in the upper farfield (Figure 3-21). This distribution pattern differed from those exhibited during 1983 and 1984, when blueback herring were most abundant in the lower farfield. Reasons for this change are at present unknown. Unlike the other anadromous species, blueback herring were abundant in the creeks (mean density of 10.6/1000 m^3 compared to 1.4/1000 m^3 in the river; Table 3-6). Steel Creek contributed large amounts of blueback herring ichthyoplankton to the Savannah River during 1985 (Table 3-9), as it did during 1983 and 1984 (Paller et al. 1984, 1985).

The number of blueback herring larvae in the Savannah River (excluding transects below RM 89.3) during 1985 (mean of 1.4/1000 m^3) was roughly equivalent to that during 1984 (mean of 1.7/1000 m^3, excluding transects below RM 89.3) but much lower than during 1983 (mean of 7.1/1000 m^3, excluding transects below RM 89.3). Much of this difference is probably attributable to river level. River levels were well below flood stage during most of April 1984 and April 1985. In contrast, the Savannah River was flooded during April 1983, which was that year's peak spawning

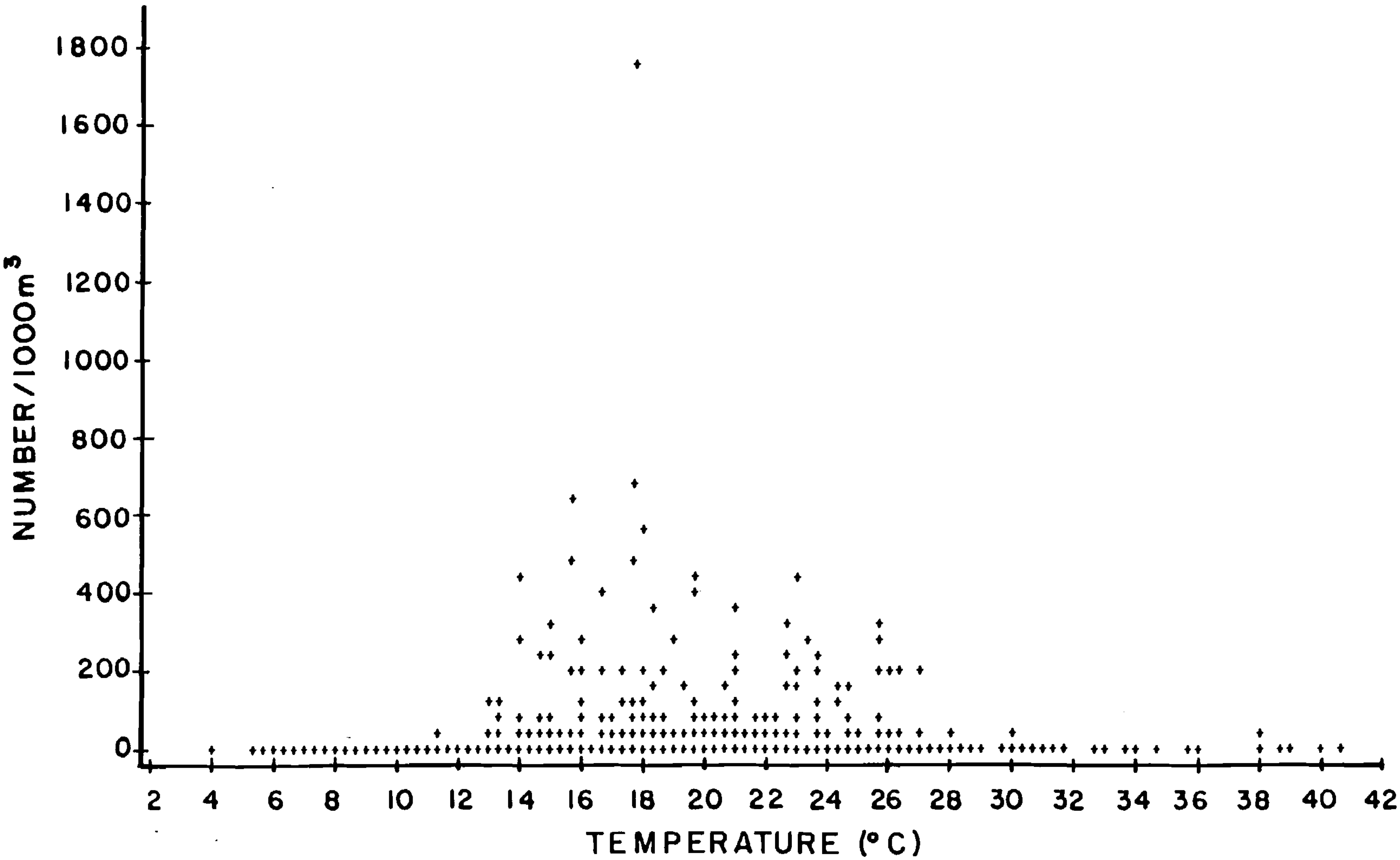


Figure 3-20. Density of blueback herring ichthyoplankton (no./1000 m^3) collected at different temperatures (°C) in the Savannah River study area. (RIVICMXT and RIVICDT). February - July 1985.

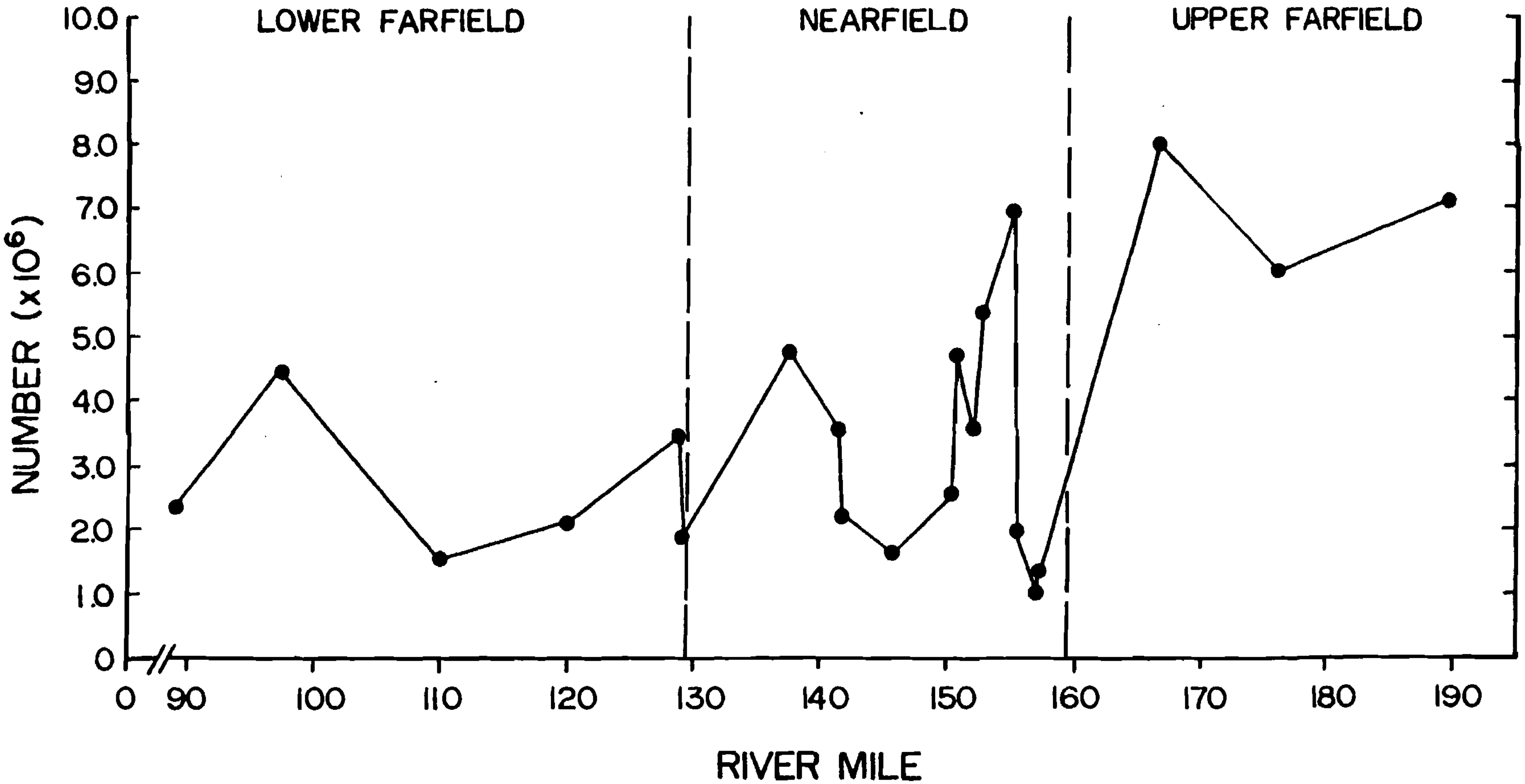


Figure 3-21. Number of blueback herring ichthyoplankton transported through Savannah River sampling transects (RIVIRAN-X). February - July 1985.

month for blueback herring. Flood conditions increase the availability of swamps and flooded lowlands, both of which constitute important spawning areas for blueback herring (Frankensteen 1976).

3.1.4.4 Gizzard and/or Threadfin Shad

Gizzard and/or threadfin shad larvae were the most abundant taxonomic group in the study area composing 35.5% of all larvae and 2.2% of all eggs collected during 1985 (Table 3-1). In addition, the category "unidentified Clupeidae" (12.7% of all larvae) probably consisted mainly of gizzard and/or threadfin shad, since blueback herring, the only other important taxon in this category, were not abundant (5.4%). Gizzard and threadfin shad are important because they serve as a link between predatory fishes and the energy sources at the base of the food web, such as detritus and plankton (Pflieger 1975).

Gizzard and/or threadfin shad larvae were not collected in any numbers until April (Table 3-22). Densities were low in April (mean of 1.5 organisms/1000 m^3), peaked in May (27.5/1000 m^3), then declined in June (8.8/1000 m^3) and July (0.1/1000 m^3). Most spawning occurred between 16°C and 25°C (Figure 3-22). These temperatures and spawning times are comparable to those observed in 1984 (Paller et al. 1985).

Gizzard and/or threadfin shad densities averaged 221.6/1000 m^3 in the oxbows, 6.0/1000 m^3 in the river, 4.3/1000 m^3

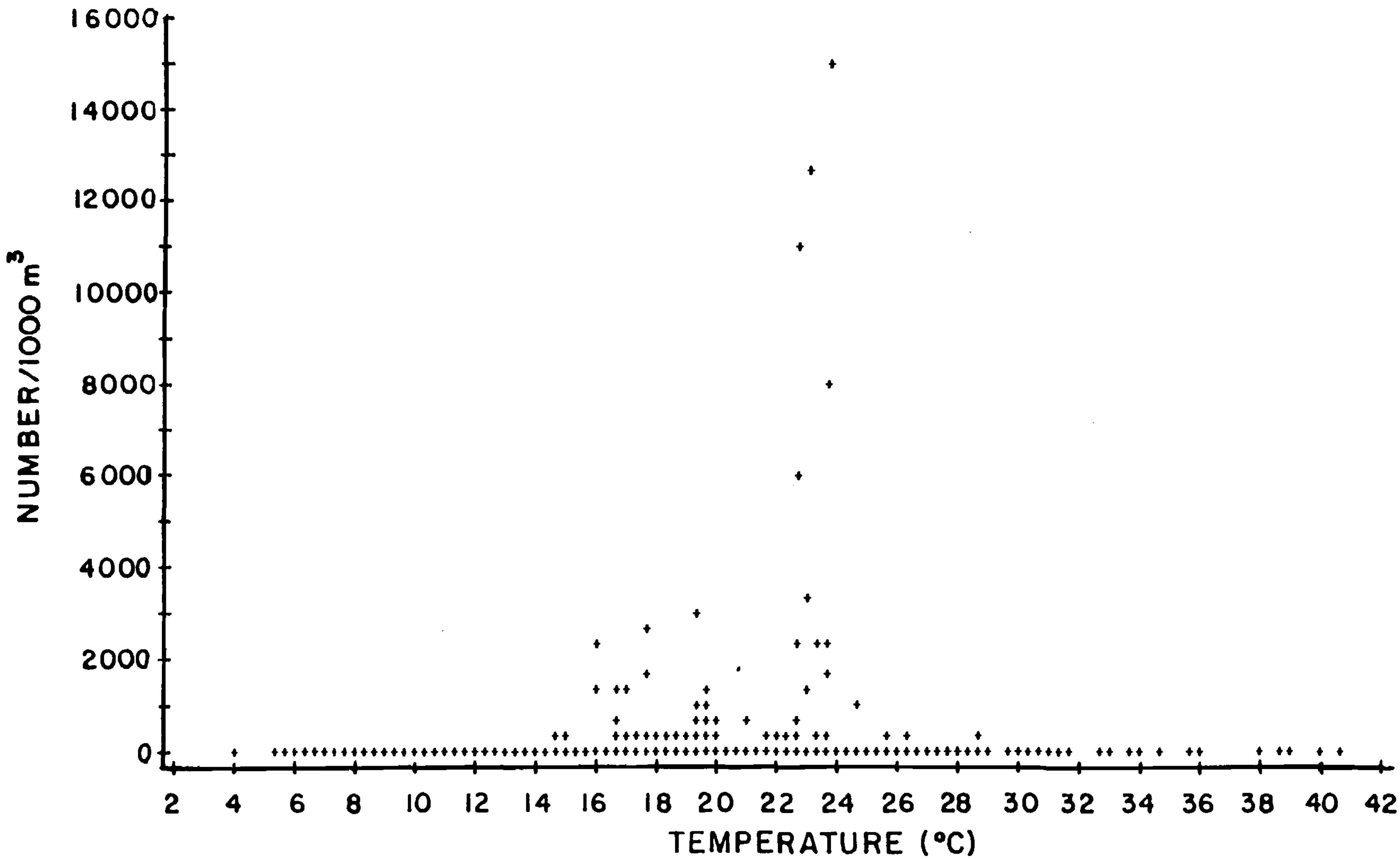


Figure 3-22. Density of gizzard and/or threadfin shad (no./1000 m^3) collected at different temperatures (^oC) in the Savannah River study area. (RIVICMXT and RIVICDT). February - July 1985.

in the creeks, and 5.0/1000 m^3 in the intake canals (Table 3-6). These data indicate that gizzard shad spawned in all the major habitats in the study area, but made particular use of the oxbows, particularly the oxbow at RM 100.2. High gizzard and/or threadfin shad densities were also observed in the oxbows during 1984 (Paller et al. 1985). Gizzard and/or threadfin shad density in the Savannah River was 6.0/1000 m^3 during 1985, slightly higher than during 1984 (4.0/1000 m^3, excluding transects below RM 89.3), but less than during 1983 (14.3/1000 m^3, excluding transects below RM 89.3).

3.1.4.5 Sunfish

Sunfish (Lepomis and unidentified sunfishes) larvae were one of the most abundant types in the study area, constituting 13.2% of all larvae collected (no eggs were identified as those of sunfish; Table 3-1). Sunfish spawning peaked in April, May, and June, and was still occurring at decreased levels in July (Tables 3-21 through 3-25). Sunfish spawning in July is not unusual, since some species (such as bluegill) normally spawn throughout the summer (Pflieger 1975).

Sunfish larvae occurred over a wide range of water temperatures (11 - 30°C; Figure 3-23), probably because the category "sunfishes" includes many species with varied optimal spawning temperatures. A few sunfish larvae were collected at temperatures of approximately 33°C in the thermal creeks. While some of these larvae may have drifted into thermal areas from other sources, the

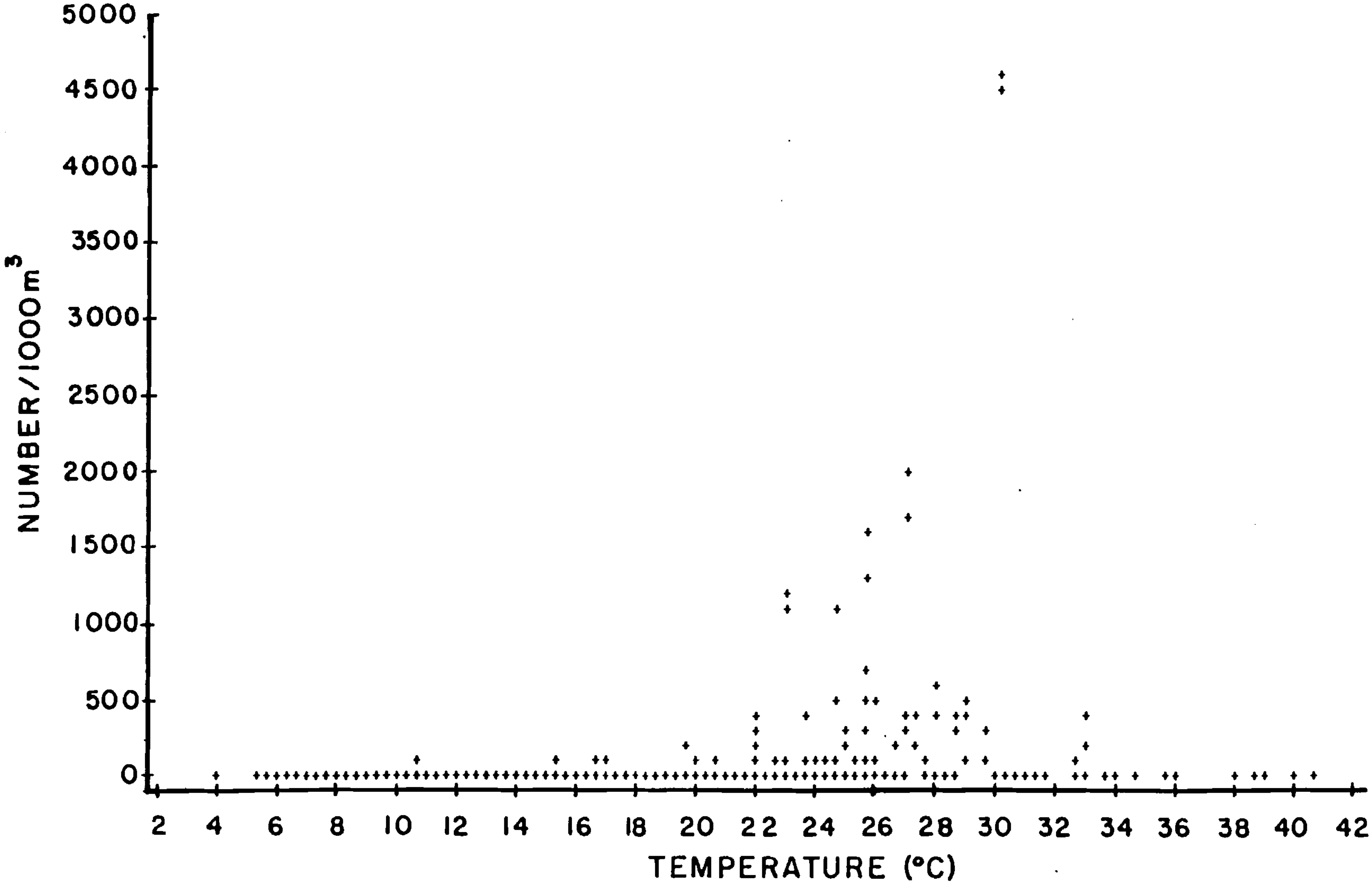


Figure 3-23. Density of sunfish ichthyoplankton (no./1000 m^3) collected at different temperatures (°C) in the Savannah River study area. (RIVICMXT and RIVICDT). February - July 1985.

sunfishes may make greater use of mildly thermal areas than most other species. A fairly similar relationship between sunfish density and temperatures was observed during 1984, with most spawning occurring between 14 and 28°C and a few larvae being collected at temperatures exceeding 30°C.

Sunfish (unidentified plus Lepomis) densities averaged 96.5/1000 m^3 in the oxbows, 0.6/1000 m^3 in the river, 6.7/1000 m^3 in the creeks, and 0.2/1000 m^3 in the intake canals (Table 3-6), indicating that the oxbows are important spawning areas for sunfish (especially the oxbow at RM 100.2). Sunfish larvae were also observed in high densities in the oxbows during 1984. Their mean densities in 1984 were 49.2/1000 m^3 in the oxbows, 17.2/1000 m^3 in the creeks, 4.0/1000 m^3 in the river (3.2/1000 m^3 excluding the transects below RM 89.3), and 1.4/1000 m^3 in the intake canals (Paller et al. 1985).

Except at the oxbows, sunfish densities were lower in 1985 than in previous years. This decrease may be related to low water levels in 1985 (Figure 3-15). Low water levels in the rivers and creeks would tend to reduce spawning habitat by eliminating coves, backwaters, and shallows where larvae and eggs are sheltered from strong currents. Low water levels in the oxbows would not necessarily have a deleterious effect, however, since currents are minimal in most of the oxbows at all but the highest water levels.

3.1.4.6 Minnows and crappie

Neither minnows nor crappie were abundant in the study area during 1985. Minnows constituted 4.3% of all the ichthyoplankton collected during 1985, and crappie, 1.9% (Table 3-1). Mean density in the Savannah River was 2.2/1000 m^3 for minnows and 0.2/1000 m^3 for crappie (Table 3-6). However, both taxa were very abundant during 1984, with minnows and crappie each composing 13.5% of all ichthyoplankton collected (Paller et al. 1985). Mean density for minnows and crappie in the Savannah River (excluding transects below RM 89.3) were 6.2/1000 m^3 and 3.2/1000 m^3, respectively, during 1984. The reduced abundance of minnows and crappie during 1985 may be due to low water levels. Both taxa peaked in abundance during flood periods in 1984 (crappie during March and minnows during May). Flooding did not occur in 1985 except for a brief period during early February, before spawning really began (Figure 3-15). Studies show that the spawning success of many fishes is increased when water levels are high (Martin et al. 1981, Krykhtin 1975). This provides favorable habitat for species that spawn over vegetation and those that require quiet waters for nursery habitat.

3.1.4.7 Sturgeon

Two species of sturgeon, the Atlantic sturgeon and the shortnose sturgeon, occur in the Savannah River. The Atlantic sturgeon is a large fish often exceeding 3 m in length (Jones et al. 1978). The shortnose sturgeon is smaller, seldom exceeding 1.3 m in total length. Extremely rare, it is listed as an endangered species by the federal government and by both South Carolina and Georgia. In the past several years, adult shortnose sturgeon have been collected in the Savannah River about 10 miles south of the SRP boundary (T. Smith, South Carolina Wildlife and Marine Resources Department; pers. comm.).

Seven sturgeon larvae were collected from the study area during 1985 (Table 3-32). Two were probably shortnose sturgeon and five were probably Atlantic sturgeon. However, differentiating the larvae of shortnose sturgeon and Atlantic sturgeon can be difficult because of their similar appearance and because of the paucity of information concerning the early life stages of these species. The sturgeon larvae were taken from the river at RMs 155.4, 166.6, 157.3, 141.7, 157.0, 120.0, and 176.0. The shortnose sturgeon larvae were taken during March, and the Atlantic sturgeon larvae during April (Table 3-32). The total number of sturgeon larvae collected by ECS since 1982 is 43 (14 during 1982, 13 during 1983, 9 during 1984, and 7 during 1985). Most were collected during the routine daytime sampling program.

Table 3-32. Larval sturgeon collected from the Savannah River by ECS during 1982, 1983, 1984 and 1985.

1982						1983					
Collection date	River Mile	Sample location[a]	Identity[b]	River temp. (°C)	River elev. (ft.)	Collection date	River Mile	Sample location[a]	Identity[b]	River temp. (°C)	River elev. (ft.)
3/12	157.3	CT	Sh	12.5	85.9	3/09	79.9	WB	Sh	16.0	94.9
3/26	157.3	CB	Sh	13.2	84.2	3/22	155.4	CB	Sh	12.5	91.9
4/21	150.8	CB	Atl	17.8	83.5	3/22	157.1	WT	Sh	11.5	92.5
4/22	155.2	EB	Atl	15.2	86.3	3/22	155.3	ET	Sh	11.5	92.5
4/22	155.2	ET	Atl	15.2	86.3	3/22	155.2	ET	Sh	11.3	92.5
4/22	155.2	EB	Atl	15.2	86.3	3/23	97.5	WT	Sh	12.6	92.5
4/22	157.0	WB	Atl	15.2	86.3	3/29	155.2	CT	Atl	12.5	90.6
4/22	157.0	EB	Atl	15.3	86.3	4/26	129.1	CB	Atl	14.4	94.0
5/21	155.4	CB	Atl	20.3	83.2	5/03	157.0	WB	Atl	18.1	86.5
5/21	155.4	CB	Atl	20.3	83.2	5/10	155.4	CB	Atl	17.5	84.5
5/21	157.0	CB	Atl	20.2	83.2	5/17	150.4	EB	Atl	22.5	84.3
5/21	157.3	CT	Atl	20.2	83.2	5/18	69.9	EB	Atl	21.5	84.6
5/21	157.3	CB	Atl	20.2	83.2	6/14	150.8	CB	Atl	20.5	83.8
8/12	157.3	CT	Atl	21.0	84.7						

[a]Samples were taken in mid-channel (C), near the South Carolina bank (E) and near the Georgia bank (W). Samples were also taken near the top (T) and near the bottom (B) of the water column.
[b]Sh = shortnose sturgeon. Atl = Atlantic sturgeon.

Table 3-32. (continued). Larval sturgeon collected from the Savannah River by ECS during 1982, 1983, 1984 and 1985.

1984						1985					
Collection date	River Mile	Sample location[a]	Identity[b]	River temp. (°C)	River elev. (ft.)	Collection date	River Mile	Sample location[a]	Identity[b]	River temp. (°C)	River elev. (ft.)
3/28	120.0	EB	Sh	15.0	89.3	3/19	155.4	WB	Sh	12.0	83.6
4/04	110.0	CB	Sh	15.5	88.6	3/26	166.6	EB	Sh	12.8	83.3
4/23	176.0	WB	Atl	14.0	92.9	4/09	157.3	EB	Atl	14.1	83.3
4/24	152.0	CB	Atl	14.5	93.3	4/16	141.7	EB	Atl	16.5	83.3
5/02	176.0	WB	Atl	15.8	94.5	4/16	157.0	WB	Atl	16.0	83.3
5/23	110.0	WB	Atl	20.5	86.6	4/24	120.0	CB	Atl	20.5	84.1
5/29	157.0	WB	Atl	20.4	86.1	4/30	176.0	WT	Atl	18.6	82.8
5/29	152.2	WB	Atl	20.5	86.1						
5/29	152.2	EB	Atl	20.5	86.1						

[a]Samples were taken in mid-channel (C), near the South Carolina bank (E) and near the Georgia bank (W). Samples were also taken near the top (T) and near the bottom (B) of the water column.
[b]Sh = shortnose sturgeon. Atl = Atlantic sturgeon.

3.2 ENTRAINMENT

Cooling water for SRP C- and K- Reactors and make-up water for Par Pond is pumped from the Savannah River at the 1G and 3G pumphouses, while the D area coal-fired power plant receives cooling water from the 5G pumphouse. Ichthyoplankton from the river are entrained into the cooling water system with the water. Entrainment of the ichthyoplankton depends on several factors, including the density of organisms in the river, the amount of spawning in the intake canals, the volume of water withdrawn by each pumphouse, and in the case of the 1G intake, the density of organisms in Upper Three Runs Creek.

3.2.1 Methods for Calculating Entrainment Estimates

A description of the sampling methods for ichthyoplankton is presented in Section 2.0 of this report. The average density of larvae (no./1000 m^3) in the six surface (two from each bank and mid-channel) and two bottom samples from each intake canal was used to calculate entrainment of larvae at the 1G and 3G pumphouses. The average density of larvae in six surface and six bottom samples (three duplicates from top and bottom) collected at RM 155.4 (the upstream river transect closest to the 5G intake) was used to calculate entrainment of larvae at the 5G pumphouse, which has no intake canal. Weekly samples were collected in the intake canals and the river from February through July 1985. The number of larvae entrained per weekly interval (sample day to sample day) was calculated by multiplying the volume of water pumped at each pumphouse during the week by the mean density of larvae from the appropriate canal or river transect for the sample days beginning and ending each week-long interval. The total entrainment of larvae for each pumphouse was calculated by summing the entrained larvae for each interval.

The calculation of entrainment of fish eggs from the Savannah River into the three pumphouses was not as direct as the calculation of larval entrainment. Few eggs were actually collected in the canals. Generally, freshwater fish have demersal rather than planktonic eggs. The only exceptions to this in the Savannah River drainage are American shad (Jones et al. 1978) and striped bass (Hardy 1978). The reduced current velocity in the intake canals allows the suspended eggs to settle out of the water column (McFarlane 1982). Silt settles over these eggs and they are assumed to die. The entrainment losses were calculated assuming that fish eggs that settle out of the water column and those actually entrained by the pumps are assumed to be lost. Thus, egg entrainment estimates are based not on egg densities within the canals (which would not include eggs that already settled to the bottom), but on egg densities at the river transects just above the canals.

The density of eggs entering the 1G canal was not calculated directly from the upstream river transect (RM 157.3), because a portion of the water entering the 1G canal (RM 157.1) comes from Upper Three Runs Creek (RM 157.2). The relative contribution of Upper Three Runs Creek and the river to the 1G intake canal water was estimated in 1985 by measuring sodium concentrations in the river upstream of Upper Three Runs Creek, in Upper Three Runs Creek, and in the mixed water coming out of the pump (Appendix 4). Sodium concentrations in the river are ordinarily higher than in Upper Three Runs Creek; therefore, the relative contributions of these sources of water to the 1G intake canal can be calculated from these data. During the six-month sampling period, Upper Three Runs Creek contributed an average of 29.52% of the water in the 1G canal, while the remainder was Savannah River water. The percentage of water from each source was multiplied by the density of eggs from each source to get a weighted average density of fish eggs entering the 1G canal.

To test the adequacy of using the average egg density at all six sampling points in the river (i.e., near-top and near-bottom at right bank, left bank, and center locations) for estimating egg entrainment at the 1G, 3G, and 5G pumphouses, two-way analysis of variance was used to determine if there were any vertical or horizontal differences in the egg density at RM 157.3 and RM 155.4. When the analysis included all eggs, there were significant differences ($p \leq 0.05$) in horizontal egg distribution at RM 155.4 (above the 3G and 5G intakes) in March and April (Table 3-33) and at RM 157.3 (above the 1G intake) in May (Table 3-34). There were no significant vertical density differences. When only American shad eggs were considered, there were significant horizontal density differences ($p \leq 0.05$) at RM 155.4 in March and April (Table 3-35) and at RM 157.3 in April (Tables 3-36), but no

Table 3-33. Mean monthly densities (no./1000 m^3) for all fish eggs at RM 155.4. Locations underlined by the same line are not significantly different ($p \leq 0.05$). February - July 1985.

	Top			Bottom		
Month	South Carolina bank	Center	Georgia bank	South Carolina bank	Center	Georgia bank
February	0.0	0.0	0.0	0.0	0.0	0.0
March[a]	0.0	19.2	5.3	0.0	20.5	1.8
April[a]	25.8	109.4	43.4	37.4	170.8	29.0
May	97.4	106.6	157.1	95.1	157.6	120.1
June	16.5	11.0	23.4	9.3	25.5	17.6
July	0.0	3.9	0.0	0.0	0.0	4.7

NOTE: RIVIC15 was used to compute the data and tests presented in this table.

[a]Horizontal density differences are significant ($p \leq 0.05$).

Table 3-34. Mean monthly densities (no./1000 m^3) for all fish eggs at RM 157.3. Locations underlined by the same line are not significantly different ($p \leq 0.05$). February - July 1985.

	Top			Bottom		
Month	South Carolina bank	Center	Georgia bank	South Carolina bank	Center	Georgia bank
February	0.0	0.0	0.0	0.0	0.0	0.0
March	4.0	14.2	10.9	21.0	32.9	12.9
April	178.0	252.3	56.4	374.1	344.9	120.1
May[a]	35.8	77.8	52.4	42.7	100.9	91.6
June	17.6	26.1	12.6	25.3	47.0	35.0
July	0.0	0.0	0.0	0.0	0.0	0.0

NOTE: RIVIC15 was used to compute the data and the tests presented in this table.

[a]Horizontal density differences are significant ($p \leq 0.05$).

Table 3-35. Mean monthly densities (no./1000 m^3) for American shad eggs at RM 155.4. Locations underlined by the same line are not significantly different ($p \leq 0.05$). February - July 1985.

	Top			Bottom		
Month	South Carolina bank	Center	Georgia bank	South Carolina bank	Center	Georgia bank
February	0.0	0.0	0.0	0.0	0.0	0.0
March[a]	0.0	19.2	5.3	0.0	20.5	1.8
April[a]	24.8	101.6	27.2	29.4	157.1	21.9
May	15.1	31.2	32.2	25.0	62.0	34.4
June	7.1	4.3	8.5	6.9	18.7	2.0
July	0.0	0.0	0.0	0.0	0.0	0.0

NOTE: RIVIC15 was used to compute the data and the tests presented in this table.

[a]Horizontal density differences are significant ($p \leq 0.05$).

Table 3-36. Mean monthly densities (no./1000 m^3) for American shad eggs at RM 157.3. Locations underlined by the same line are not significantly different ($p \leq 0.05$). February - July 1985.

	Top			Bottom		
Month	South Carolina bank	Center	Georgia bank	South Carolina bank	Center	Georgia bank
February	0.0	0.0	0.0	0.0	0.0	0.0
March	4.0	14.2	10.9	18.5	32.9	12.9
April[a]	59.7	111.2	52.1	50.9	281.2	107.0
May	35.8	74.2	41.4	40.7	88.9	82.3
June	17.6	14.6	10.8	14.3	40.9	18.0
July	0.0	0.0	0.0	0.0	0.0	0.0

NOTE: RIVIC15 was used to compute the data and the tests presented in this table.

[a]Horizontal density differences are significant ($p \leq 0.05$).

significant vertical density differences. When only the density of striped bass eggs was analyzed, there were no significant vertical or horizontal differences ($p \leq 0.05$). For months when there were significant density differences between the South Carolina bank and the center and Georgia bank sampling locations, only South Carolina bank densities were used in the egg entrainment calculations. When such differences were lacking, the average of the data at the South Carolina bank, center, and Georgia bank locations was used in the entrainment estimates.

The egg entrainment per interval was calculated by multiplying the total volume of water pumped during the sampling interval by the appropriate mean egg density. The total entrainment of fish eggs was estimated by summing the entrained eggs during each sampling interval.

3.2.2 Larval Entrainment

Larval fish collected during entrainment sampling were identified to the lowest possible taxon; in some instances it was difficult to identify larval fish to the species level. There were, however, at least 6 taxa entrained at the SRP pumphouses in 1985 (Table 3-37). The most common larval fish entrained were suckers, which constituted 43% of the larval fish entrained (Table 3-37). The single most abundant taxon was spotted sucker, with a total of 4.6×10^6 larvae (42.7%) entrained at the three pumphouses. Other abundant taxa were gizzard and/or threadfin shad (22.0%), unidentified Clupeidae (11.4%), and carp (10.3%; Table 3-

Table 3-37. Number and percent composition of larval fish entrained at the 1G, 3G, and 5G pumphouses. February - July 1985.

Taxa	1G No. x10^3	1G Percent composition	3G No. x10^3	3G Percent composition	5G No. x10^3	5G Percent composition	Total No. x10^3	Total Percent composition
unid. Clupeidae	379	9.9	797	12.5	69	10.1	1245	11.4
blueback herring	195	5.1	198	3.1	21	3.1	414	3.8
American shad	46	1.2	9	0.1	5	0.7	60	0.6
gizzard and/or threadfin shad	563	14.7	1660	26.0	171	25.2	2394	22.0
unid. Cyprinidae	122	3.2	225	3.5	61	8.9	408	3.8
carp	341	8.9	687	10.8	89	13.1	1117	10.3
spotted sucker	1,835	48.0	2585	40.5	223	32.8	4643	42.7
unid. suckers	-	-	24	0.4	6	0.9	30	0.4
Others	341	8.9	195	3.0	39	5.3	575	5.1
Total	3,822	99.9	6,380	99.9	684	100.1	10,882	100.1

NOTE: RIVIC14 was used to compute the data presented in this table.

37). Generally, there were no differences in species composition between the three pumphouses. On 19 March 1985 at RM 155.4, a single sturgeon larva was collected. Since larvae collected at this river transect were used to calculate entrainment at the 5G pumphouse, it is possible that sturgeon larvae were entrained during 1985. However, since this was only a single larva on a single occasion, no estimate of the total number of sturgeon larvae entrained can be made.

Total larval fish entrained due to SRP activities from February - July 1985 was calculated to be 10.9×10^6. The 1G pumphouse entrained 3.8×10^6 larvae (35%), 6.4×10^6 larvae (59%) were entrained at the 3G pumphouse, and 0.7×10^6 larvae (6%) at the 5G pumphouse (Tables 3-38, 3-39 and 3-40).

Maximum larval entrainment occurred during the interval between 28 May and 4 June, with a combined entrainment at all three pumphouses of 2.0×10^6 larval fish (Tables 3-38, 3-39, and 3-40). During this period, the most abundant taxa were gizzard and/or threadfin shad, unidentified Clupeidae, carp, and spotted suckers, which represented 37.8%, 20.1%, 17.7%, and 13.4% of the total, respectively (Tables 3-41 through 3-43). Peak entrainment resulted from high larval densities coupled with large amounts of water pumped from the river. The average daily intake for the three pumphouses combined was 2.3×10^6 m^3 of water. During this

Table 3-38. Estimate of total larval fish entrainment at the 1G pumphouse. February - July 1985.

Interval	Total volume pumped ($\times 1000\ m^3$)	Mean larval density (No./1000 m^3)[a]	Total Larvae
2/05 - 2/12	6,930	0.8	5,544
2/12 - 2/19	7,358	0.8	5,886
2/19 - 2/26	8,406	0.0	0
2/26 - 3/05	8,320	0.0	0
3/05 - 3/12	7,903	0.0	0
3/12 - 3/19	5,526	5.8	32,051
3/19 - 3/26	6,441	5.8	37,358
3/26 - 4/02	7,473	24.6	183,836
4/02 - 4/09	6,345	47.6	302,022
4/09 - 4/16	6,401	39.4	252,199
4/16 - 4/23	7,938	31.4	249,253
4/23 - 4/30	6,272	43.7	274,086
4/30 - 5/07	6,102	53.6	327,067
5/07 - 5/14	6,907	33.1	228,622
5/14 - 5/21	6,668	44.7	298,060
5/21 - 5/28	7,601	84.9	645,325
5/28 - 6/04	7,561	78.8	595,807
6/04 - 6/11	7,230	34.5	249,435
6/11 - 6/18	7,088	5.3	37,566
6/18 - 6/25	4,937	1.3	6,418
6/25 - 7/02	4,032	5.4	21,773
7/02 - 7/09	4,641	6.7	31,095
7/09 - 7/16	4,478	3.8	17,016
7/16 - 7/23	3,674	2.5	9,185
7/23 - 7/30	4,338	3.2	13,882
Total number of fish			3,823,486[b]

NOTE: Data from RIVIC12 was used to compute the data presented in this table.

[a] Mean density was calculated with Upper Three Runs contributing 29.52% of the 1G intake water and Savannah River contributing 70.48% of the intake water at 1G.

[b] Due to rounding errors in the calculation of the values presented in this table, totals in this table and Table 3-41 do not agree.

Table 3-39. Estimate of total larval fish entrainment at the 3G pumphouse. February - July 1985.

Interval	Total volume pumped ($x1000\ m^3$)	Mean larval density ($No./1000\ m^3$)	Total Larvae
2/05 - 2/12	7,413	0.0	0
2/12 - 2/19	8,017	0.0	0
2/19 - 2/26	7,770	0.0	0
2/26 - 3/05	7,701	1.1	8,471
3/05 - 3/12	7,249	2.2	15,948
3/12 - 3/19	7,137	2.4	17,129
3/19 - 3/26	8,399	1.3	10,919
3/26 - 4/02	9,205	23.4	215,397
4/02 - 4/09	9,485	48.8	462,868
4/09 - 4/16	6,281	31.6	198,480
4/16 - 4/23	7,138	33.2	236,982
4/23 - 4/30	8,640	56.4	487,296
4/30 - 5/07	8,017	59.5	477,012
5/07 - 5/14	8,970	52.3	469,131
5/14 - 5/21	8,485	60.9	516,736
5/21 - 5/28	9,052	104.7	947,744
5/28 - 6/04	9,717	136.8	1,329,286
6/04 - 6/11	9,605	85.8	824,109
6/11 - 6/18	8,566	17.1	146,479
6/18 - 6/25	3,243	3.3	10,702
6/25 - 7/02	4,482	1.1	4,930
7/02 - 7/09	5,808	0.0	0
7/09 - 7/16	5,935	0.0	0
7/16 - 7/23	6,435	0.0	0
7/23 - 7/30	7,117	0.0	0
Total number of fish			6,379,620[a]

NOTE: Data from RIVIC12 was used to compute the data presented in this table.

[a]Due to rounding errors in the calculation of the values presented in this table, totals in this table and Table 3-42 do not agree.

Table 3-40. Estimate of total larval fish entrainment at the 5G pumphouse. February - July 1985.

Interval	Total volume pumped (x1000 m^3)	Mean larval density (No./1000 m^3)	Total Larvae
2/05 - 2/12	1,520	0.0	0
2/12 - 2/19	1,520	0.0	0
2/19 - 2/26	1,520	0.0	0
2/26 - 3/05	1,520	0.0	0
3/05 - 3/12	1,520	0.0	0
3/12 - 3/19	1,520	0.9	1,368
3/19 - 3/26	1,520	1.5	2,280
3/26 - 4/02	1,520	11.3	17,176
4/02 - 4/09	1,520	29.8	45,296
4/09 - 4/16	1,520	27.0	41,040
4/16 - 4/23	1,520	21.1	32,072
4/23 - 4/30	1,520	28.0	42,560
4/30 - 5/07	1,520	28.7	43,624
5/07 - 5/14	1,520	50.3	76,456
5/14 - 5/21	1,520	78.7	119,624
5/21 - 5/28	1,520	84.8	128,896
5/28 - 6/04	1,520	55.8	84,816
6/04 - 6/11	1,520	19.1	29,032
6/11 - 6/18	1,520	6.8	10,336
6/18 - 6/25	1,520	1.1	1,672
6/25 - 7/02	1,520	0.8	1,216
7/02 - 7/09	1,520	0.8	1,216
7/09 - 7/16	1,520	0.7	1,064
7/16 - 7/23	1,520	0.7	1,064
7/23 - 7/30	1,520	0.7	1,064
Total number of fish			681,872[a]

NOTE: Data from RIVIC12 was used to compute the data presented in this table.

[a]Due to rounding errors in the calculation of the values presented in this table, totals in this table and Table 3-43 do not agree.

Table 3-41. Larvae taxa entrained at the 1G pumphouse. February - July 1985.

Interval	unid. Clupeidae	blueback herring	American shad	threadfin and/or gizzard shad	unid. Cyprinidae	carp	spotted suckers	unid. crappie	unid. darters	other	total
2/05-2/12	0	0	0	0	0	0	0	0	0	5370	5370
2/12-2/19	0	0	0	0	0	0	0	0	0	5701	5701
2/19-2/26	0	0	0	0	0	0	0	0	0	0	0
2/26-3/05	0	0	0	0	0	0	0	0	0	0	0
3/05-3/12	0	0	0	0	0	0	0	0	0	0	0
3/12-3/19	0	0	0	0	0	0	0	5796	20194	5796	31786
3/19-3/26	0	0	0	0	0	0	0	6756	23538	6756	37050
3/26-4/02	0	76359	0	0	0	0	87847	0	19320	0	183526
4/02-4/09	0	64833	0	0	0	0	221067	0	16404	0	302304
4/09-4/16	0	0	0	0	0	0	230483	0	21566	0	252049
4/16-4/23	0	0	0	0	0	0	213365	0	35919	0	249284
4/23-4/30	0	0	6330	24791	13001	0	222682	0	7250	0	274054
4/30-5/07	0	0	11693	39189	12648	0	252478	0	5535	5535	327078
5/07-5/14	0	0	6265	23143	18256	6085	157763	0	6265	10722	228499
5/14-5/21	25577	0	10004	68445	24995	40588	123981	0	0	4302	297892
5/21-5/28	112239	0	11403	180314	8404	150269	165740	0	8404	8404	645177
5/28-6/04	145187	27458	0	169115	9317	127243	83314	0	8359	25826	595819
6/04-6/11	59804	26526	0	58042	16373	16378	55783	0	0	16703	249339
6/11-6/18	0	0	0	0	7317	0	20694	0	0	9398	37409
6/18-6/25	0	0	0	0	0	0	0	0	0	6546	6546
6/25-7/02	16881	0	0	0	0	0	0	0	0	4888	21769
7/02-7/09	19431	0	0	0	5887	0	0	0	0	5634	30952
7/09-7/16	0	0	0	0	5680	0	0	0	11247	0	16927
7/16-7/23	0	0	0	0	0	0	0	0	9227	0	9227
7/23-7/30	0	0	0	0	0	0	0	0	9424	4312	13736
Totals	379119	194906	45695	563039	121878	340563	1835197	12552	202652	125893	3821494
Percent	9.9	5.1	1.2	14.7	3.2	8.9	48.0	0.3	5.3	3.3	99.9

NOTE: RIVKEY was used to compute the data presented in this table.

Table 3-42. Larvae taxa entrained at the 3G pumphouse. February - July 1985.

Interval	unid. Clupeidae	blueback herring	American shad	threadfin and/or gizzard shad	unid. Cyprinidae	carp	spotted suckers	unid. suckers	unid. crappie	unid. darters	other	total
2/05-2/12	0	0	0	0	0	0	0	0	0	0	0	0
2/12-2/19	0	0	0	0	0	0	0	0	0	0	0	0
2/19-2/26	0	0	0	0	0	0	0	0	0	0	0	0
2/26-3/05	0	0	0	0	0	0	0	0	0	0	8694	8694
3/05-3/12	0	0	0	0	0	0	0	0	7829	0	8184	16013
3/12-3/19	0	0	0	0	0	0	0	0	7708	9100	0	16808
3/19-3/26	0	0	0	0	0	0	0	0	0	10709	0	10709
3/26-4/02	0	0	0	0	0	0	215350	0	0	0	0	215350
4/02-4/09	0	0	0	0	9729	0	443375	0	0	0	9729	462833
4/09-4/16	0	0	0	14769	6443	0	170560	0	0	0	6443	198215
4/16-4/23	0	0	0	37468	10080	0	180878	0	0	0	0	228426
4/23-4/30	0	8477	0	64676	12200	0	388028	0	0	0	0	473381
4/30-5/07	24811	20613	0	86533	0	10333	344157	0	0	11827	0	486447
5/07-5/14	38231	0	0	72297	10282	64980	271924	0	0	11188	0	469541
5/14-5/21	84430	0	0	118640	47476	104559	139374	0	12501	0	0	518168
5/21-5/28	179532	0	0	315443	49098	256810	133339	0	13337	0	0	947559
5/28-6/04	243939	66674	0	563544	33051	213803	175341	0	0	0	44320	1340672
6/04-6/11	176022	84991	0	364319	34729	19112	98868	12797	0	0	32983	823821
6/11-6/18	46265	17021	0	22724	11491	17045	20551	11413	0	0	0	146510
6/18-6/25	3516	0	3638	0	0	0	3516	0	0	0	0	10670
6/25-7/02	0	0	5028	0	0	0	0	0	0	0	0	5028
7/02-7/09	0	0	0	0	0	0	0	0	0	0	0	0
7/09-7/16	0	0	0	0	0	0	0	0	0	0	0	0
7/16-7/23	0	0	0	0	0	0	0	0	0	0	0	0
7/23-7/30	0	0	0	0	0	0	0	0	0	0	0	0
Totals	796746	197776	8666	1660413	224579	686642	2585261	24210	41375	42824	110353	6378845
Percent	12.5	3.1	0.1	26.0	3.5	10.8	40.5	0.4	0.6	0.7	1.7	99.0

NOTE: RIVKEY was used to compute the data presented in this table.

Table 3-43. Larvae taxa entrained at the 5G pumphouse. February - July 1985.

Interval	unid. Clupeidae	blueback herring	American shad	threadfin and/or gizzard shad	unid. Cyprinidae	carp	spotted suckers	unid. suckers	unid. crappie	unid. darters	other	total
2/05-2/12	0	0	0	0	0	0	0	0	0	0	0	0
2/12-2/19	0	0	0	0	0	0	0	0	0	0	0	0
2/19-2/26	0	0	0	0	0	0	0	0	0	0	0	0
2/26-3/05	0	0	0	0	0	0	0	0	0	0	0	0
3/05-3/12	0	0	0	0	0	0	0	0	0	0	0	0
3/12-3/19	0	0	0	0	0	0	0	0	0	0	1360	1360
3/19-3/26	0	0	0	0	0	0	886	0	0	0	1360	2246
3/26-4/02	0	0	0	0	0	0	15958	0	0	1135	0	17093
4/02-4/09	0	0	0	0	0	0	44118	0	0	1135	0	45253
4/09-4/16	0	1374	0	0	5453	0	31721	0	0	2472	0	41020
4/16-4/23	0	4856	0	1989	9260	0	11862	0	0	4097	0	32064
4/23-4/30	0	3482	0	9397	5657	0	19263	1987	0	1624	1151	42561
4/30-5/07	1293	1020	0	17181	3847	0	16112	1987	977	0	1151	43568
5/07-5/14	3512	2276	1094	21246	15459	10890	18331	0	977	0	2664	76449
5/14-5/21	15487	1257	2403	32619	14878	23406	25586	0	0	0	5188	120824
5/21-5/28	24956	0	1309	46904	1416	29567	20271	1034	0	870	5281	131608
5/28-6/04	16690	1042	0	32807	1088	17951	12175	1034	0	870	0	83657
6/04-6/11	6087	2036	0	8134	2296	3220	6042	0	0	0	1097	28912
6/11-6/18	1086	994	0	1086	1208	2320	999	0	0	0	2710	10403
6/18-6/25	0	0	0	0	0	0	0	0	0	0	1613	1613
6/25-7/02	0	1249	0	0	0	0	0	0	0	0	0	1249
7/02-7/09	0	1249	0	0	0	0	0	0	0	0	0	1249
7/09-7/16	0	0	0	0	0	1040	0	0	0	0	0	1040
7/16-7/23	0	0	0	0	0	1040	0	0	0	0	0	1040
7/23-7/30	0	0	0	0	0	0	0	0	0	0	989	989
Totals	69111	20835	4806	171363	60562	89434	223324	6042	1954	12203	24564	684198
Percent	10.1	3.0	0.7	25.0	8.9	13.1	32.6	0.9	0.3	1.8	3.6	100.0

NOTE: RIVKEY was used to compute the data presented in this table.

interval, 3G pumphouse had its highest larval density (136.8 larvae/1000 m^3) and the largest total intake volume (9.7×10^6 m^3) for 1985.

The period of maximum entrainment at the 1G pumphouse occurred from 21 May through 28 May (Table 3-38). The 0.6×10^6 larvae entrained during this period represented 16.9% of the total larvae entrained at the 1G pumphouse. During this period, the larvae consisted mainly of gizzard and/or threadfin shad, spotted suckers, and carp, which represented 27.9%, 25.7%, and 23.3% of the total, respectively. The mean density during this period was 84.9 larvae/1000 m^3, which was the highest mean density that occurred at 1G during the 1985 sampling season.

At the 3G pumphouse, the period of maximum entrainment was 28 May through 4 June (Table 3-39). Approximately 1.3×10^6 larvae were entrained during this period, which represents 20.8% of all of the larvae entrained at 3G pumphouse (Table 3-42). The most common taxa during this period were gizzard and/or threadfin shad (42.3%), unidentified Clupeidae (18.2%), carp (15.9%), and spotted suckers (13.1%, Table 3-42),

Maximum entrainment at the 5G pumphouse occurred during the interval between 21 May and 28 May (Table 3-40). The 0.1×10^6 larvae entrained during this interval constituted 18.9% of all the larvae entrained at the 5G pumphouse. The major taxon during the interval was gizzard and/or threadfin shad, which represented

35.6% of the total for the interval (Table 3-43). Other common taxa were carp (22.4%), unidentified Clupeidae (19.0%), and spotted suckers (15.4%)

The estimated total number of larval fish entrained by the Savannah River Plant during February through July 1985 (10.9×10^6) was the lowest in five years of available entrainment information (Table 3-44). Relatively low entrainment of larvae during 1985 was due to fewer larvae being present in the intake canals. Larval densities in the intake canals are determined by the amount of spawning in the canals and by larval densities in the river (and in Upper Three Runs Creek for the 1G canal). In 1983 and 1984, at least two taxa--gizzard and/or threadfin shad and crappie--appeared to be spawning in the intake canals, since the larvae of these species were present in higher densities in the canal than in the river. In 1985, most taxa, except spotted suckers, exhibited lower densities in the intake canals than in the river, possibly because the intake canals were recently dredged, thus reducing their value as spawning habitat. Larval densities were also comparatively low in the Savannah River during 1985. The low densities may have been related to low river level, which reduced the spawning and nursery habitat for species that prefer to spawn in flooded or sheltered areas.

3.2.3 Egg Entrainment

The total fish egg entrainment from February through July was estimated to be 15.1×10^6, of which 7.8×10^6 eggs (51.4%) were

Table 3-44. Summary of available estimates of fish larvae and eggs entrained from the Savannah River by the SRP pumphouses.

Year	Larvae	Eggs	Total Ichthyoplankton
1985[a]	10.8×10^6	15.1×10^6	25.9×10^6
1984[b]	17.6×10^6	5.8×10^6	23.4×10^6
1983[c]	28.1×10^6	9.1×10^6	37.2×10^6
1982[d]	17.9×10^6	18.1×10^6	36.0×10^6
1977[e]	19.6×10^6	6.8×10^6	26.4×10^6

[a]This report
[b]Paller et al. 1985
[c]Paller et al. 1984
[d]ECS 1983
[e]McFarlane et al. 1978

entrained at the 1G pumphouse, 6.2 x 10^6 (41.4%) at the 3G pumphouse, and 1.1 x 10^6 eggs (7.3%) at the 5G pumphouse (Table 3-45). American shad eggs represented 46.8% of the total eggs entrained, followed by striped bass eggs (26.2%) and other eggs (24.7%, Table 3-45).

The relative abundance of entrained eggs differed between pumphouses. American shad eggs represented 53.2% (4.1 x 10^6 eggs) of the total eggs entrained at 1G pumphouse (Table 3-45) and were the most common taxon, both at 1G and at all three pumphouses combined. The next most common taxon at 1G was "other eggs", which represented 40.5% (3.1 x 10^6 eggs) of the total entrainment at the 1G pumphouse. "Other eggs" consisted of unidentifiable eggs and a few identifiable eggs other than the four most abundant species. While striped bass represented 26.2% of the total egg entrainment, the taxon made up only 3.6% of the entrainment at 1G. Striped bass was the dominant species at the 3G and 5G pumphouses, representing 50.4% (3.1 x 10^6 eggs) of the total eggs at the 3G pumphouse and 48.4% (0.5 x 10^6 eggs) of the total eggs at the 5G pumphouse. American shad eggs represented 39.8% (2.5 x 10^6 eggs) of the eggs entrained at the 3G pumphouse and 41.6% (0.5 x 10^6 eggs) of the eggs entrained at the 5G pumphouse.

Maximum entrainment (all pumphouses summed) occurred between 16 April and 23 April 1985, when the total number of eggs entrained was 3.3 x 10^6 eggs (Tables 3-46, 3-47, and 3-48). The dominant taxa during this period were other eggs and American shad

Table 3-45. Number and percent composition of fish eggs entrained at the 1G, 3G and 5G pumphouses. February - July 1985.

Taxa	1G Pumphouse No. $x10^3$	1G Pumphouse Percent Composition	3G Pumphouse No. $x10^3$	3G Pumphouse Percent Composition	5G Pumphouse No. $x10^3$	5G Pumphouse Percent Composition	Total No. $x10^3$	Total Percent Composition
blueback herring	122	1.6	11	0.2	2	0.2	135	0.9
American shad	4122	53.2	2485	39.8	457	41.6	7064	46.8
gizzard and/or threadfin shad	91	1.2	98	1.6	17	1.6	206	1.4
striped bass	280	3.6	3145	50.4	531	48.4	3956	26.2
Other	3138	40.5	508	8.1	90	8.3	3736	24.8
Total	7753	100.1	6247	100.1	1097	100.1	15097	100.1

NOTE: RIVKEY and RIVIC14 were used to compute the data presented in this table.

Table 3-46. Estimate of total fish egg entrainment at the 1G pumphouse. February - July 1985.

Interval	Total volume pumped ($\times 1000\ m^3$)	Mean egg density ($No./1000\ m^3$)[a]	Total Eggs
2/05 - 2/12	6,930	0.0	0
2/12 - 2/19	7,358	0.0	0
2/19 - 2/26	8,406	0.0	0
2/26 - 3/05	8,320	0.9	7,488
3/05 - 3/12	7,903	2.1	16,596
3/12 - 3/19	5,526	5.7	32,498
3/19 - 3/26	6,441	72.0	141,702
3/26 - 4/02	7,473	30.8	230,168
4/02 - 4/09	6,345	32.3	204,944
4/09 - 4/16	6,401	66.0	422,466
4/16 - 4/23	7,938	363.4	2,884,669
4/23 - 4/30	6,272	354.6	2,224,051
4/30 - 5/07	6,102	55.4	338,050
5/07 - 5/14	6,907	37.8	261,085
5/14 - 5/21	6,668	33.0	220,044
5/21 - 5/28	7,601	21.9	166,462
5/28 - 6/04	7,561	24.3	183,732
6/04 - 6/11	7,230	25.2	182,196
6/11 - 6/18	7,088	20.9	148,139
6/18 - 6/25	4,937	13.2	65,163
6/25 - 7/02	4,037	2.5	10,080
7/02 - 7/09	4,641	1.6	7,426
7/09 - 7/16	4,478	1.6	7,165
7/16 - 7/23	3,674	0.0	0
7/23 - 7/30	4.338	0.0	0
Total			7,754,124[b]

NOTE: Data from RIVIC12 was used to calculate the data presented in this table.

[a]Mean density was calculated with Upper Three Runs contributing 29.52% of the 1G intake water and Savannah River contributing 70.48% of the intake water at 1G.

[b]Due to rounding errors in the calculation of values presented in this table, totals in this table do not agree with Table 3-49.

Table 3-47. Estimate of fish total egg entrainment at the 3G pumphouse. February - July 1985.

Interval	Total volume pumped ($x1000\ m^3$)	Mean egg density ($No./1000\ m^3$)[a]	Total Eggs[a]
2/05 - 2/12	7,413	0.0	0
2/12 - 2/19	8,017	0.0	0
2/19 - 2/26	7,770	0.0	0
2/26 - 3/05	7,701	0.0	0
3/05 - 3/12	7,249	0.0	0
3/12 - 3/19	7,137	0.0	0
3/19 - 3/26	8,399	0.0	0
3/26 - 4/02	9,205	2.2	20,251
4/02 - 4/09	9,485	9.0	85,365
4/09 - 4/16	6,281	31.3	196,595
4/16 - 4/23	7,138	45.9	327,624
4/23 - 4/30	8,640	45.3	391,392
4/30 - 5/07	8,017	48.7	390,428
5/07 - 5/14	8,970	146.1	1,310,517
5/14 - 5/21	8,485	132.5	1,124,263
5/21 - 5/28	9,052	98.6	892,527
5/28 - 6/04	9,717	104.8	1,018,342
6/04 - 6/11	9,605	32.4	311,202
6/11 - 6/18	8,566	15.7	134,486
6/18 - 6/25	3,243	2.1	6,810
6/25 - 7/02	4,482	2.8	12,550
7/02 - 7/09	5,808	1.5	8,712
7/09 - 7/16	5,935	0.8	4,748
7/16 - 7/23	6,435	1.4	9,009
7/23 - 7/30	7,117	0.6	4,270
Total			6,249,091

NOTE: Data from RIVIC12 was used to compute the data presented in this table.

[a]Due to rounding errors in the calculations of values presented in this table, totals in this table do not agree with Table 3-50.

Table 3-48. Estimate of total fish egg entrainment at the 5G pumphouse. February - July 1985.

Interval	Total volume pumped (x1000 m^3)	Mean egg density (No./1000 m^3)[a]	Total Eggs[a]
2/05 - 2/12	1,520	0.0	0
2/12 - 2/19	1,520	0.0	0
2/19 - 2/26	1,520	0.0	0
2/26 - 3/05	1,520	0.0	0
3/05 - 3/12	1,520	0.0	0
3/12 - 3/19	1,520	0.0	0
3/19 - 3/26	1,520	0.0	0
3/26 - 4/02	1,520	2.2	3,344
4/02 - 4/09	1,520	9.0	13,680
4/09 - 4/16	1,520	31.3	47,576
4/16 - 4/23	1,520	45.9	69,768
4/23 - 4/30	1,520	45.3	68,856
4/30 - 5/07	1,520	48.7	74,024
5/07 - 5/14	1,520	146.1	222,072
5/14 - 5/21	1,520	132.5	201,400
5/21 - 5/28	1,520	98.6	149,872
5/28 - 6/04	1,520	104.8	159,269
6/04 - 6/11	1,520	32.4	49,248
6/11 - 6/18	1,520	15.7	23,867
6/18 - 6/25	1,520	2.1	3,192
6/25 - 7/02	1,520	2.8	4,256
7/02 - 7/09	1,520	1.5	2,280
7/09 - 7/16	1,520	0.8	1,216
7/16 - 7/23	1,520	1.4	2,128
7/23 - 7/30	1,520	0.6	912
Total			1,096,960

NOTE: Data from RIVIC12 was used to compute the data presented in this table.

[a]Due to rounding errors in the calculation of values presented in this table, totals in this table do not agree with Table 3-51.

eggs (50.7% and 42.1% of the total, respectively; Tables 3-49, 3-50, and 3-51). At the 3G and 5G pumphouses, the dominant species was American shad, which represented approximately 76% of the entrained eggs at both pumphouses during this interval.

Maximum egg entrainment at the 1G pumphouse occurred between 16 April and 23 April, when 2.9×10^6 eggs were entrained (Table 3-46). The most abundant taxa during this interval was other eggs (55.8% of the total) and American shad (37.4%; Table 3-49). Maximum entrainment at 3G and 5G pumphouses occurred between 7 May and 14 May 1985, when 1.3×10^6 eggs and 0.2×10^6 eggs, respectively, were entrained at the pumphouses (Tables 3-47 and 3-48). Since egg entrainment estimates for both pumphouses were based on samples from the same river transect, percent composition was the same at both pumphouses. The dominant species during the peak entrainment period were striped bass (62.5% of the total eggs entrained) and American shad (35.4% of the total eggs entrained; Tables 3-50 and 3-51).

3.2.4 Impact of Entrainment on River Ichthyoplankton

In evaluating the impact of the SRP on the Savannah River fisheries, the relationship between entrained ichthyoplankton and river ichthyoplankton susceptible to entrainment was examined. The total ichthyoplankton entrained at the 1G pumphouse was 11.5×10^6 organisms. A rough estimate of the total ichthyoplankton that passed the 1G canal was 211.6×10^6 organisms, which includes total ichthyoplankton calculated to be at

Table 3-49. Egg taxa totals entrained at the 1G pumphouse. February - July 1985.

Interval	Blueback herring	American shad	Threadfin and/or gizzard shad	Striped bass	Other	Total
2/05 - 2/12	0	0	0	0	0	0
2/12 - 2/19	0	0	0	0	0	0
2/19 - 2/26	0	0	0	0	0	0
2/26 - 3/05	0	7,488	0	0	0	7,488
3/05 - 3/12	0	16,596	0	0	0	16,596
3/12 - 3/19	0	31,498	0	0	0	31,498
3/19 - 3/26	0	127,940	0	0	13,875	141,815
3/26 - 4/02	26,537	153,149	0	0	50,375	230,061
4/02 - 4/09	31,584	135,415	0	0	38,155	205,154
4/09 - 4/16	18,508	381,482	6,763	0	15,478	422,231
4/16 - 4/23	30,480	1,078,700	8,386	156,364	1,610,899	2,884,829
4/23 - 4/30	14,895	812,829	0	123,546	1,272,517	2,223,787
4/30 - 5/07	0	324,277	0	0	13,848	338,125
5/07 - 5/14	0	251,649	0	0	9,150	260,799
5/14 - 5/21	0	220,150	0	0	0	220,150
5/21 - 5/28	0	155,840	10,644	0	0	166,484
5/28 - 6/04	0	135,966	34,513	0	13,090	183,569
6/04 - 6/11	0	112,616	26,833	0	42,917	183,366
6/11 - 6/18	0	114,629	3,880	0	29,801	148,310
6/18 - 6/25	0	57,990	0	0	7,163	65,153
6/25 - 7/02	0	4,122	0	0	5,850	9,972
7/02 - 7/09	0	0	0	0	7,514	7,514
7/09 - 7/16	0	0	0	0	7,250	7,250
7/16 - 7/23	0	0	0	0	0	0
7/23 - 7/30	0	0	0	0	0	0
Total	122,004	4,122,336	91,019	279,910	3,137,882	7,753,151

NOTE: RIVKEY was used to compute the data presented in this table.

Table 3-50. Egg taxa totals entrained at the 3G pumphouse. February - July 1985.

Interval	Blueback herring	American shad	Threadfin and/or gizzard shad	Striped bass	Other	Total
2/05 - 2/12	0	0	0	0	0	0
2/12 - 2/19	0	0	0	0	0	0
2/19 - 2/26	0	0	0	0	0	0
2/26 - 3/05	0	0	0	0	0	0
3/05 - 3/12	0	0	0	0	0	0
3/12 - 3/19	0	0	0	0	0	0
3/19 - 3/26	0	0	0	0	0	0
3/26 - 4/02	0	20,251	0	0	0	20,251
4/02 - 4/09	0	85,365	0	0	0	85,365
4/09 - 4/16	0	170,789	8,511	0	17,031	196,331
4/16 - 4/23	0	248,844	9,672	25,044	44,284	327,844
4/23 - 4/30	0	330,664	0	30,320	30,176	391,160
4/30 - 5/07	5,378	384,873	0	0	0	390,251
5/07 - 5/14	6,018	463,832	0	818,556	21,717	1,310,113
5/14 - 5/21	0	329,634	0	774,297	20,542	1,124,473
5/21 - 5/28	0	135,015	8,447	722,095	27,137	892,688
5/28 - 6/04	0	131,874	26,595	775,143	84,493	1,018,105
6/04 - 6/11	0	132,037	31,971	0	146,944	310,952
6/11 - 6/18	0	39,252	13,059	0	82,244	134,555
6/18 - 6/25	0	6,791	0	0	0	6,791
6/25 - 7/02	0	5,861	0	0	6,613	12,474
7/02 - 7/09	0	0	0	0	8,570	8,570
7/09 - 7/16	0	0	0	0	4,633	4,633
7/16 - 7/23	0	0	0	0	8,892	8,892
7/23 - 7/30	0	0	0	0	4,278	4,278
Total	11,396	2,485,082	98,255	3,145,455	507,554	6,247,742

NOTE: RIVKEY was used to compute the data presented in this table.

Table 3-51. Egg taxa totals entrained at the 5G pumphouse. February - July 1985.

Interval	Blueback herring	American shad	Threadfin and/or gizzard shad	Striped bass	Other	Total
2/05 - 2/12	0	0	0	0	0	0
2/12 - 2/19	0	0	0	0	0	0
2/19 - 2/26	0	0	0	0	0	0
2/26 - 3/05	0	0	0	0	0	0
3/05 - 3/12	0	0	0	0	0	0
3/12 - 3/19	0	0	0	0	0	0
3/19 - 3/26	0	0	0	0	0	0
3/26 - 4/02	0	3,411	0	0	0	3,411
4/02 - 4/09	0	13,670	0	0	0	13,670
4/09 - 4/16	0	41,331	0	0	4,121	47,512
4/16 - 4/23	0	52,990	2,060	5,334	9,430	69,814
4/23 - 4/30	0	58,172	2,060	5,334	5,309	68,815
4/30 - 5/07	1,020	72,969	0	0	0	73,989
5/07 - 5/14	1,020	78,598	0	138,707	3,680	222,005
5/14 - 5/21	0	59,051	0	138,707	3,680	201,438
5/21 - 5/28	0	22,672	1,418	121,253	4,557	149,900
5/28 - 6/04	0	20,629	4,160	121,253	13,217	159,259
6/04 - 6/11	0	20,895	5,059	0	23,254	49,208
6/11 - 6/18	0	6,944	2,318	0	14,594	23,856
6/18 - 6/25	0	3,183	0	0	0	3,183
6/25 - 7/02	0	1,986	0	0	2,243	4,229
7/02 - 7/09	0	0	0	0	2,243	2,243
7/09 - 7/16	0	0	0	0	1,187	1,187
7/16 - 7/23	0	0	0	0	2,101	2,101
7/23 - 7/30	0	0	0	0	914	914
Total	2,040	456,501	17,075	530,588	90,530	1,096,734

NOTE: RIVKEY was used to compute the data presented in this table.

RM 157.3 and at the mouth of Upper Three Runs Creek (Table 3-7). At 1G, 5.5% of the total ichthyoplankton that passed the intake canal was entrained.

The ichthyoplankton that passed just upstream of the 3G canal and the 5G pumphouse was calculated to be 132.8×10^6 organisms. The 12.6×10^6 ichthyoplankton entrained at the 3G pumphouse was 9.5% of the total ichthyoplankton. At the 5G pumphouse, the 1.6×10^6 ichthyoplankton entrained represented 1.2% of the ichthyoplankton that passed the intake structure.

The impact of entrainment on the Savannah River ichthyoplankton that passed by the SRP was estimated by calculating the total entrainment for all three pumphouses (25.7×10^6 organisms) as a percent of the total ichthyoplankton upstream of all three intake structures (211.6×10^6 organisms). In 1985, 12.1% of the total susceptible ichthyoplankton was entrained. This was more than the 8.3% of the total ichthyoplankton entrained in 1983 (Paller et al. 1984). In a comparison of SRP activities with other industrial operations on large rivers, the 1985 entrainment value of 12.3% of the total ichthyoplankton is substantially higher than the 4% entrainment observed by Marcy (1976) at the Connecticut Yankee Plant on the Connecticut River and the 3.2% average daily entrainment observed by Hergenrader et al. (1982) at the Fort Calhoun Station on the Missouri River.

During the 1985 spawning season, the percentage of river water withdrawn for SRP operations ranged from 0.4% at the 5G intake on 9 February 1985 to 10.6% (percentages calculated from data provided by SRL) at the 3G pumphouse on 26 May 1985. The total percent of river water pumped by all three pumphouses ranged from 3.2% on 8 February 1985 to 20.7% 26 May 1985. For all dates, the average volume taken in by all three pumphouses was 12.2% of the river flow. This average is consistent with the 13.3% reported for 1982 by ECS (1983), but was higher than the 7.7% observed in 1983 (Paller et al. 1984) and the 7% in 1984 (Paller et al. 1985). The relatively high withdrawals during 1982 and 1985 are partly due to the fact that river discharge was low during both years.

With the reactivation of L-Reactor and with all reactors operating, there will be a 42.3% increase in water pumped from the Savannah River through 1G and 3G pumphouses (DOE 1984). Based on this projected increase in water intake, the 1985 entrainment estimates would be increased from 10.8×10^6 larvae to 15.4×10^6 larvae and from 14.9×10^6 eggs to 21.2×10^6 eggs.

3.3 DIURNAL STUDIES

Ichthyoplankton densities in large turbulent rivers reflect both riverine spawning and the transport of eggs and larvae out of feeder streams, oxbows, and floodplain swamps along the length of the river. The density of ichthyoplankton often varies over 24 h as a result of behavioral characteristics of the fish species present in the ichthyoplankton (Gale and Mohr 1978).

Fish spawning is temporally regulated. Some species, including American shad and striped bass, spawn near dusk or dawn (Breder and Rosen 1966; Williams and Bruger 1972), while other species, such as gizzard shad, spawn primarily during daylight hours (Grasser 1979). These differences in spawning times can strongly influence the density of ichthyoplankton, particularly eggs, in the water column at any given time.

While most larvae have limited motility in rapidly flowing water, many can swim sufficiently well to leave protected areas and be caught in the current. The movement of larvae from protected areas generally occurs at night (Gale and Mohr 1978; Hergenrader et al. 1982) and is reflected in higher nighttime densities in ichthyoplankton collections.

Because there is natural diurnal variation in the density of ichthyoplankton in a river, daily production and transport rates, as well as entrainment calculations based on ichthyoplankton densities taken once during daylight hours and extrapolated to a 24 h period, are commonly underestimated.

As part of this study of the Savannah River, the diurnal variation in ichthyoplankton density was examined in the area of the SRP intakes. While it is recognized that the limited diurnal sampling done during this study is insufficient to justify recalculation of entrainment rates and total density of ichthyoplankton in the river, it does provide an indication of the magnitude of the bias of the estimates.

3.3.1 Methods

Diurnal collections were made once during March, April, May, and June 1985 at four river transects between RM 155.2 and 157.3 (RM 155.2, RM 155.4, RM 157.0, and RM 157.3) and in the 1G (RM 157.1) and 3G (RM 155.3) intake canals. The sampling methodology used for these collections is described in Section 2.0 of this report. The diurnal collections were made during four 6-h intervals in a 24 h period: 0600 - 1200 h, 1200 - 1800 h, 1800 - 2400 h, and 2400 - 0600 h. Periods 0600 - 1200 h and 1200 - 1800 h were day collections, while periods 1800 - 2400 h and 2400 - 0600 h were night collections.

3.3.2 Diurnal Distribution of Ichthyoplankton

In March, the ichthyoplankton community was dominated by American shad eggs during the day and sunfish larvae during the night (Table 3-52). The appearance of American shad eggs in the daylight collections was probably the result of an early morning spawn, since American shad typically spawn near dawn or dusk (Williams and Bruger 1972). Sunfishes and pirate perch were numerous at night. Analysis of variance and of Scheffe's tests indicated that night densities were significantly ($p \leq 0.05$)

Table 3-52. Relative abundance of ichthyoplankton collected during the diel sampling program in March. February - July 1985.

	March															
	0600 - 1200 h				1200 - 1800 h				1800 - 2400 h				2400 - 0600 h			
Taxa	Eggs		Larvae		Eggs		Larvae		Eggs		Larvae		Eggs		Larvae	
Common Name	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
unid. Clupeidae	0		0		0		0		0		1	2.4	0		1	5.6
unid. herring/ shad	0		1	9.1	0		0		0		0		0		0	
American shad	37	100.0	0		16	100.0	0		8	100.0	0		14	77.8	0	
gizzard and/or threadfin shad	0		0		0		0		0		0		0		0	
minnow (Cyprinidae)	0		0		0		0		0		0		0		0	
carp	0		0		0		0		0		0		0		0	
spotted sucker	0		0		0		0		0		0		0		0	
unid. sucker	0		0		0		0		0		0		0		0	
unid. catfish	0		0		0		0		0		0		0		0	
swampfish	0		0		0		0		0		0		0		0	
pirate perch	0		0		0		0		0		15	36.6			10	55.6
brook silverside	0		0		0		0		0		0		0		0	
striped bass	0		0		0		0		0		0		0		0	
unid. sunfish	0		0		0		0		0		24	58.6			1	5.6
unid. crappie	0		2	18.2	0		0		0		0		0		0	
yellow perch	0		0		0		0		0		0		0		0	
unid. darter	0		6	54.5	0		1	100.0	0		1	2.4	0		6	33.2
sturgeon	0		1	9.1	0		0		0		0		0		0	
unknown	0		1	9.1	0		0		0		0		4	22.2	0	
Total	37	100.0	11	100.0	16	100.0	1	100.0	8	100.0	41	100.0	18	100.0	18	100.0
Mean Temperatures	10.5				10.9				11.1				10.8			

NOTE: RIVICDIU was used to compute the data presented in this table.

higher than day densities (Table 3-53). Temperatures during the March diel sample ranged from 10.5 to 11.1°C.

In April, densities were significantly greater ($p \leq 0.05$) during the night than during the day ($p \leq 0.05$; Table 3-53). Peak densities were from 1800 through 2400 h. American shad constituted most of the eggs, and spotted suckers most of the larvae from all time periods (Table 3-54). April ichthyoplankton densities were over 20 times higher than those in March, indicating much greater spawning (Figure 3-24). Temperatures during the April diel sample ranged from 18.0 to 18.5°C.

In May, fish larvae constituted over 50% of the total ichthyoplankton density in each diel collection (Table 3-55). Predominant types of larvae included spotted suckers, gizzard and/or threadfin shad, unidentified Clupeidae, and carp. American shad eggs were abundant in the 2400 - 0600 h sample (45% of all ichthyoplankton). As in preceding months, densities were significantly higher during the night than during the day ($p \leq 0.05$; Table 3-53). Mean water temperatures during this series of samples ranged from 19.0 to 20.1°C.

In June (the last month of diel sampling), a relatively large number of American shad eggs was collected in the 2400 to 0600 diel period (Table 3-56). This made night ichthyoplankton densities 6 times higher than day densities (significant at $p \leq 0.05$; Table 3-53). The general reduction in total density

Table 3-53. Results of Scheffe's test for average density (no./1000 m^3) of ichthyoplankton during four diurnal time periods. Tests were conducted using transformed data but mean densities are presented as arithmetic averages (no./1000 m^3). Time periods underscored by the same line are not significantly different ($p \leq 0.05$). February - July 1985.

Month	Sampling Hours 0600-1200	Sampling Hours 1200-1800	Sampling Hours 1800-2400	Sampling Hours 2400-0600	Time Periods Day (0600-1800)	Time Periods Night (1800-0600)
March	15.1	5.2	21.4	12.6	10.1	17.0
April	180.6	512.6	575.0	531.8	346.6	553.4
May	119.8	92.3	246.7	493.6	106.0	370.1
June	11.9	6.9	29.8	92.2	9.4	61.0

NOTE: DIURGLM was used to compute the tests presented in this table.

Table 3-54. Relative abundance of ichthyoplankton collected during the diurnal sampling program in April. February - July 1985.

Taxa	April															
	0600-1200 h				1200-1800 h				1800-2400 h				2400-0600 h			
	Eggs		Larvae		Eggs		Larvae		Eggs		Larvae		Eggs		Larvae	
Common name	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
unid. Clupeidae			1	1.0							1	0.3			5	1.4
unid. herring/ shad	9	2.3	18	18.6	2	0.3	3	3.8	9	1.0	4	1.4	6	0.4	7	1.9
American shad	294	73.7	2	2.1	560	83.2	2	2.6	391	42.7	8	2.7	1133	79.8	2	0.6
gizzard and/or threadfin shad	1	0.2	4	4.1	2	0.3	8	10.3	1	0.1	5	1.7	6	0.4	12	3.3
unid. minnow			6	6.2							2	0.7			10	2.8
carp																
spotted sucker			61	62.9			54	69.2			247	84.0			302	83.9
unid. sucker			1	1.0			3	3.8			8	2.7			9	2.5
unid. catfish																
swampfish															1	0.3
pirate perch											3	1.0				
brook silverside																
striped bass	60	15.0			46	6.8			76	8.3			107	7.5		
unid. sunfish											2	0.7				
unid. crappie											1	0.3				
yellow perch							1	1.3			2	0.7			1	0.3
unid. darter			3	3.1			5	6.4			2	0.7			7	1.9
sturgeon																
unknown	35	8.8	1	1.0	63	9.4	2	2.6	439	47.9	9	3.1	168	11.8	4	1.1
Total	399	100.0	97	100.0	673	100.0	78	100.0	916	100.0	294	100.0	1420	99.9	360	100.0
Mean Temperature (^{o}C)		18.5				18.5				18.2				18.0		

NOTE: RIVICDIU was used to compute the data presented in this table.

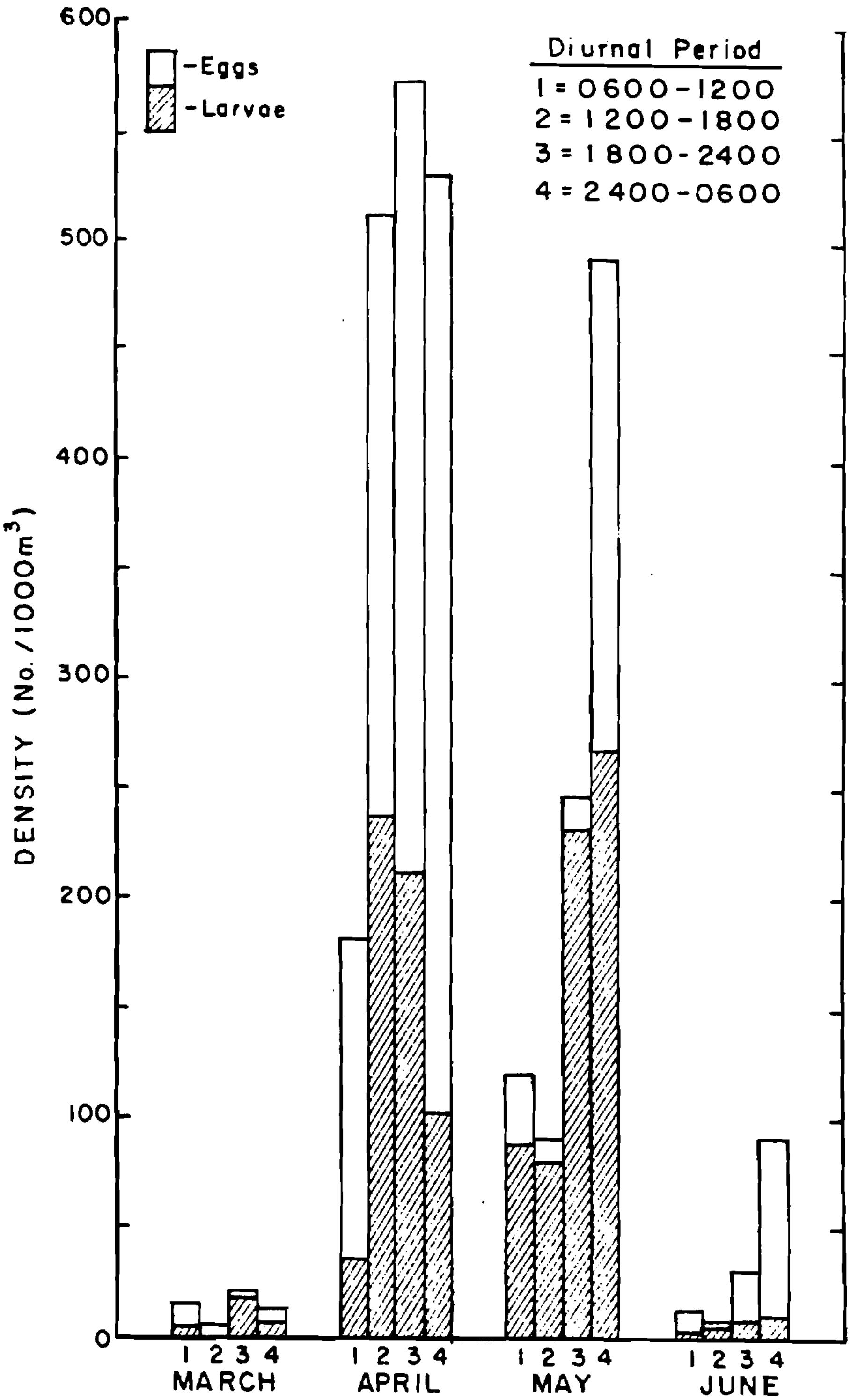


Figure 3-24. Density of larvae and eggs collected during the diel sampling program in March, April, May, and June (RIVICDIU). February - July 1985.

Table 3-55. Relative abundance of ichthyoplankton collected during the diurnal sampling program in May. February - July 1985.

Taxa	May															
	0600-1200 h				1200-1800 h				1800-2400 h				2400-0600 h			
	Eggs		Larvae		Eggs		Larvae		Eggs		Larvae		Eggs		Larvae	
Common Name	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
unid. Clupeidae			20	8.7			13	7.3			135	18.9			72	8.3
unid. herring/ shad									1	2.4	5	0.7				
American shad	90	96.8	6	2.6	35	97.2	1	0.6	40	95.2	4	0.6	693	99.3	4	0.5
gizzard and/or threadfin shad			71	30.7	1	2.8	50	27.9	1	2.4	362	50.8	3	0.4	302	34.7
unid. minnow			11	4.8			12	6.7			23	3.2			31	3.6
carp			59	25.5			50	27.9			119	16.7			112	12.9
spotted sucker			57	24.7			48	26.8			60	8.4			340	39.0
unid. sucker			1	0.4			2	1.1			1	0.1			2	0.2
unid. catfish																
swampfish																
pirate perch																
brook silverside															1	0.1
striped bass																
unid. sunfish											1	0.1			1	0.1
unid. crappie			2	0.9											3	0.4
yellow perch																
unid. darter							2	1.1			1	0.1				
sturgeon																
unknown	3	3.2	4	1.7			1	0.6			2	0.3	2	0.3	2	0.2
Total	93	100.0	231	100.0	36	100.0	179	100.0	42	100.0	713	99.9	698	100.0	870	100.0
Mean Temperature (°C)	19.0				19.7				19.7				20.1			

NOTE: RIVICDIU was used to compute the data presented in this table.

Table 3-56. Relative abundance of ichthyoplankton collected during the diel sampling program in June. February - July 1985.

	June															
	0600 - 1200 h				1200 - 1800 h				1800 - 2400 h				2400 - 0600 h			
Taxa	Eggs		Larvae		Eggs		Larvae		Eggs		Larvae		Eggs		Larvae	
Common Name	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
unid. Clupeidae			1	16.7			2	18.2			4	17.4				
unid. herring/ shad									3	5.1	1	4.4				
American shad	25	96.2			8	80.0			31	52.5	4	17.4	266	100.0	3	8.1
gizzard and/or threadfin shad							1	9.1			6	26.0				
unid. minnow							1	9.1			1	4.4			3	8.1
carp			1	16.7			4	36.4			1	4.4			2	5.4
spotted sucker							3	27.3			1	4.4				
unid. sucker			1	16.7												
unid. catfish											3	13.0			22	59.5
swampfish																
pirate perch																
brook silverside																
striped bass																
unid. sunfish			3	50.0							2	8.7			7	18.9
unid. crappie																
yellow perch																
unid. darter																
sturgeon																
unknown	1	3.8			2	20.0			25	42.4						
Total	26	100.0	6	100.1	10	100.0	11	100.1	59	100.0	23	100.1	266	100.0	37	100.0
Mean Temperatures	21.5				22.3				22.1				22.1			

NOTE: RIVICDIU was used to compute the data presented in this table.

during June indicated an end to the spawning season for most species. The water temperature during the June diel samples ranged from 21.5 to 22.3°C.

In 1985, diel collections in all months sampled indicated significantly higher densities at night than during the day. This pattern of diel distribution is similar to results found by other investigators (Gale and Mohr 1978; Hergenrader et al. 1982) and is consistent with the findings from this portion of the Savannah River during 1984 (Paller et al 1985). During 1983, in contrast, diel collections from the Savannah River indicated higher densities during the day (Paller et al. 1985).

3.3.3 Effect of Time on Ichthyoplankton Sampling

The occurrence of relatively high ichthyoplankton densities at night and low densities during the day suggests that samples taken near dawn or dusk might contain more ichthyoplankton than samples taken during full daylight. The vast majority of ichthyoplankton samples taken during the regular sampling program were taken during full daylight, hence were not subject to this potential bias. However, because of logistic constraints, samples taken at RM 141.7 during the 1983 and 1984 regular sampling programs were generally collected early in the morning (mean military time equaled 0846 during 1983 and 0800 during 1984).

Collecting samples just after dawn at RM 141.7 may have been responsible for the comparatively high densities observed at this transect during 1983 and 1984 (Paller et al. 1984, 1985).

To obtain information on the magnitude of the time-related bias associated with density values at RM 141.7, this transect was sampled both early in the morning (mean military time equaled 0733) and in the afternoon (mean military time equaled 1511) on 11 dates during April, May, June, and July 1985. Mean density values at RM 141.7 were consistently higher in the morning than in the afternoon, with the greatest difference occurring during April (Table 3-57). Mean density at RM 141.7 during April was 267.8 organisms/1000 m^3 in the morning and 84.4/1000 m^3 in the afternoon. Differences between morning and night were somewhat smaller during May (160.5 and 108.4 organisms/1000 m^3, respectively) and June (53.4 and 32.6 organisms/1000 m^3, respectively). Reduced densities in the afternoon samples were exhibited by nearly all taxa (Table 3-58).

The preceding data suggest that the relatively high ichthyoplankton densities observed at RM 141.7 during 1983 and 1984 may have been to some degree due to temporal bias rather than spatial variations in spawning intensity. The exact magnitude of the time-related differences between RM 141.7 and adjacent transects cannot be accurately estimated, however, because the relationship between ichthyoplankton density and time of day is imperfectly understood. Thus, it is possible that time-related

Table 3-57. Ichthyoplankton densities (no./1000 m^3) in the morning (0700 - 0800 h) and afternoon (1200 - 1700 h) at RM 141.7. The samples were taken during April, May, June, and July 1985.

	0700 - 0800 h			1200 - 1700 h		
Date	Larvae	Eggs	Total	Larvae	Eggs	Total
4/09	64.0	143.2	207.1	14.2	30.0	44.1
4/16	104.9	269.2	374.1	11.3	46.9	58.2
4/30	46.8	175.5	222.3	28.7	122.4	151.0
Apr mean	71.9	196.0	267.8	18.1	66.4	84.4
5/07	30.6	162.7	193.3	24.7	78.1	102.8
5/21	83.8	72.1	155.9	63.0	68.3	131.2
5/28	56.7	75.7	132.4	25.5	65.8	91.3
May mean	57.0	103.5	160.5	37.7	70.7	108.4
6/04	56.8	72.2	128.9	22.0	85.9	107.8
6/11	6.0	47.1	53.2	3.2	11.9	15.1
6/18	17.4	5.2	22.7	0.0	3.6	3.6
6/25	3.0	5.8	8.8	1.2	2.8	3.9
Jun mean	20.8	32.6	53.4	6.6	26.1	32.6
7/02	21.3	2.9	24.2	4.7	0.0	4.7
Grand mean	44.7	93.8	138.4	18.0	46.9	64.9

NOTE: RIVICDE was used to compute the data presented in this table.

Table 3-58. Ichthyoplankton species densities (no./1000 m^3) in the morning (0700 - 0800 h) and afternoon (1200 - 1700 h) at RM 141.7. The samples were taken during April, May, June, and July 1985. February - July 1985.

Species	0700 - 0800	1200 - 1700
American shad	88.1	45.7
blueback herring	1.0	1.0
gizzard and/or threadfin shad	8.1	3.8
minnows (Cyprinidae)	1.4	1.5
spotted sucker	20.8	6.3
carp	6.7	2.3
Centrarchidae	0.7	0.2
sunfish (*Lepomis*)	2.4	0.5
unid. sunfish	3.1	0.8
All taxa	132.3	62.1

NOTE: RIVICDE was used to compute the data presented in this table.

differences between RM 141.7 and transects sampled somewhat later in the morning were smaller than the differences between RM 141.7 and transects sampled in the afternoon.

Steel Creek, as well as RM 141.7, may have exhibited inflated densities during 1983 and 1984 due to time of sampling. On the average, Steel Creek was sampled at 0837 in 1983 and 0716 in 1984. While early morning sampling may have inflated the estimates of ichthyoplankton abundance in Steel Creek, it is important to recognize that ichthyoplankton transport from Steel Creek into the Savannah River was many times higher than from most of the other creeks in the nearfield or upper farfield during 1983 and 1984 (Paller et al. 1984, 1985). Such differences are too great to be accounted for by temporal biases of the sort suggested by the morning and afternoon density measurements at RM 141.7. In substantiation of this, it is important to recognize that Steel Creek was sampled at an average time of 1119 during 1985 (Table 3-59), somewhat later than during 1983 (0837) or 1984 (0716), and during full daylight hours. In spite of this later sampling time, ichthyoplankton transport from Steel Creek was greater than from all other streams sampled during 1985.

Table 3-59. Mean time of sample collection at each transect during the regular sampling program. February - July 1985.

River Mile	Mean Military Time	Standard Deviation (minutes)	Range (military time)
River Transects			
89.3	1054	48	1000 - 1300
97.5	1230	42	1100 - 1400
110.0	1200	66	1000 - 1400
120.0	1054	42	1000 - 1200
128.9	1424	126	0900 - 1700
129.1	1324	90	1000 - 1600
137.7	1200	84	0900 - 1500
141.5	1024	102	0800 - 1500
141.7	0854	108	0700 - 1600
145.7	0936	42	0800 - 1100
150.4	1100	48	1000 - 1300
150.8	1312	78	1200 - 1800
152.0	1418	78	1300 - 1900
152.2	1548	66	1400 - 1800
155.2	1442	132	1000 2000
155.4	1324	108	0900 1700
157.0	1036	108	0700 1500
157.3	0918	114	0600 1600
166.6	1236	168	0900 - 1600
176.0	1230	66	1000 - 1400
187.1	1218	144	0900 - 1600
Creeks			
Buck Creek (92.6)	1206	54	1100 - 1500
Briar Creek (97.6)	1330	54	1100 - 1500
The Gaul (109.0)	1348	108	1200 - 1600
Smith Lake Creek (126.5)	1030	96	0900 - 1600
Lower Three Runs (129.0)	1512	108	1100 - 1800
Sweetwater Creek (133.5)	1324	108	1100 - 1800
Steel Creek (141.6)	1118	102	0800 1700
Four Mile Creek (150.6)	1212	66	1100 - 1700
Beaver Dam Creek (152.1)	1524	60	1400 - 1800
Upper Three Runs Creek	1036	132	0600 1700
Upper Boggy Gut Creek (162.2)	1700	0	1700 - 1700
McBean Creek (164.2)	1448	186	0900 - 1800
Hollow Creek (176.1)	1324	60	1200 - 1600
Spirit Creek (183.3)	1312	84	1100 - 1500

4.0 SUMMARY

The 1985 Savannah River ichthyoplankton sampling program extended from February through July and included 21 river transects, two intake canals, five oxbows, and the mouths of 17 tributaries between RM 89.3 and RM 187.1. River transects, intake canals, and oxbows were sampled weekly. Creeks were sampled weekly when conditions permitted. This program was a continuation of monitoring begun during 1983 and employed the same sampling sites and methodologies except for the elimination of all sample sites (3 river transects, 11 creek mouths, and 1 oxbow) below RM 89.3. The basic objective was to assess spawning activity and ichthyoplankton distribution upstream and downstream from the Savannah River Plant (SRP) in order to evaluate the possible impact of existing and proposed thermal discharges and the removal of river water for secondary cooling of nuclear reactors. Special emphasis was placed on evaluating ichthyoplankton production in Steel Creek in light of possible future impacts on this stream following the re-start of L-Reactor.

A total of 19,918 fish larvae and 15,749 fish eggs were collected during 1985. As in previous years, the dominant group was the Clupeidae (65% of all ichthyoplankton), which included the anadromous blueback herring and American shad and the non-anadromous threadfin and gizzard shad. Other abundant taxa were

the sunfishes and spotted suckers. While important during 1983 and 1984, crappie and minnows were comparatively minor components of the ichthyoplankton during 1985.

The most abundant ichthyoplankton in Steel Creek were American shad, blueback herring, and darters. The high percentage and number of American shad and blueback herring indicate that the lower reaches of Steel Creek below the swamp are a spawning area for these anadromous species. American shad and blueback herring have also been collected from Steel Creek during previous years, although American shad were never as abundant as during 1985.

An estimated 5.2 million fish larvae and eggs were transported from Steel Creek to the Savannah River during 1985. This was more than were transported from any other creek in the study area during 1985. Ichthyoplankton transport from all creeks was much lower during 1985 than during 1984 or 1983, possibly due to decreased creek discharges (79% lower during 1985 than 1984) and/or decreased spawning resulting from comparatively low water levels.

Temperatures in the mouth of Four Mile Creek were as much as 20°C higher than in the other creeks, due to reactor discharge. Ichthyoplankton sampling indicated that ichthyoplankton were largely absent from the mouth of Four Mile Creek when the reactor was operating and water temperatures high, but that fish rapidly moved into Four Mile Creek and began spawning when the reactor shut down.

Beaver Dam Creek, the other thermally-impacted SRP creek sampled during 1985, was approximately 1 - 8°C warmer than most of the creeks in the study area. Ichthyoplankton densities in Beaver Dam Creek were roughly equivalent to densities in most other creeks during March and April, but lower than in most other creeks during May, June, and July. Temperatures often exceeded 30°C during May, June, and July.

Ichthyoplankton densities in the river were characterized by pronounced temporal changes. Mean ichthyoplankton density for the entire section of river under study was 0.3 organisms/1000 m^3 in February, 18.2/1000 m^3 in March, 156.6/1000 m^3 in April, 139.4/1000 m^3 in May, 42.9/1000 m^3 in June, and 3.5/1000 m^3 in July. Statistical analysis indicated that most of the variability in ichthyoplankton density observed in this study was associated with sampling date, reflecting the influence of seasonal changes in temperature and photoperiod on spawning activity.

Larval densities in the river were generally similar near the top and bottom of the water column and across the channel; exceptions occurred at several transects where densities differed between banks. With the exception of RM 150.4, these differences were probably due to current or to localized aggregations of spawning fish in favorable habitats. At RM 150.4, approximately 0.2 km below the point where thermal discharge from C-Reactor leaves the mouth of Four Mile Creek, larval densities were reduced near the South Carolina bank. Reduced larval densities at RM 150.4 were most notable during April and were due to decreases in the number of spotted sucker larvae; other taxa were not affected. These decreases were localized at RM 150.4 and not detectable farther downstream.

Unlike larval densities, egg densities were often greater near the bottom than near the surface. In addition, they were often heterogeneously distributed across the river channel. These distribution patterns were probably due to localized spawning and hydrological factors. The density of fish eggs was not reduced near the South Carolina bank at RM 150.4.

There are three important anadromous species that spawn in the Savannah River: American shad, striped bass, and blueback herring. American shad were collected in large numbers throughout the river and were far more abundant during 1985 than during 1983 or 1984. Striped bass were about as abundant during 1985 as during 1984, peaking in numbers near the SRP. Blueback herring abundance peaked in the upper portion of the study area during 1985 instead of in the lower portion of the study area as in 1983 and 1984. Blueback herring densities were fairly similar during 1984 and 1985, but during both years were low compared to 1983. Two nonanadromous taxa, crappie and minnows, were much less abundant during 1985 than during earlier years, possibly because of exceptionally low river levels that eliminated floodplain spawning sites for these species. Floodplain spawning sites are not important for species such as American shad and striped bass, which spawn in the river channel.

Spawning trends and ichthyoplankton densities in the five oxbows sampled during 1985 were generally comparable to those in the river. The only exception was an oxbow at RM 100.2, which consistently had much higher densities than did the river. Reasons for the apparent productivity of this oxbow are unknown at present. Gizzard and threadfin shad were the dominant ichthyoplankton in the oxbows.

Diel collections from the Savannah River and intake canals during March, April, May, and June indicated significantly higher ichthyoplankton densities during the night than during the day. While this pattern was also observed during 1982 and 1984, day-night differences were more consistent during 1985. In 1983, the diel collections indicated higher densities during the day due to exceptionally large numbers of threadfin and gizzard shad larvae.

On the basis of ichthyoplankton samples taken during daylight hours, an estimated 25.9×10^6 ichthyoplankton (10.8×10^6 larvae and 15.1×10^6 eggs) were entrained during 1985. This is approximately 12.1% of the total number of ichthyoplankton that drifted past the SRP pumphouses. Total ichthyoplankton entrainment during 1985 (25.7×10^6) was fairly similar to that in 1977 (26.4×10^6) and 1984 (23.4×10^6), but less than that in 1982 (36.0×10^6) and 1983 (37.2×10^6).

5.0 THREE-YEAR SYNTHESIS

SRL/ECS studies on the ichthyoplankton of the mid and lower reaches of the Savannah River began in 1982 and ended in 1985. The 1982 studies were restricted in scope and included 7 river transects between RM 141.5 and 157.3, the two SRP intake canals, and the mouths of Steel Creek, Four Mile Creek, and Upper Three Runs Creek. The 1983 and 1984 studies included more sample stations: 26 river transects beween RM 29.3 and 187.1, 27 - 28 creek mouths, two intake canals and, in 1984, six river oxbows. The 1985 study was slightly truncated and included 21 river transects between RM 89.3 and 187.1, five river oxbows, two intake canals, and 14 creek mouths.

The Savannah River ichthyoplankton assemblage consists of a variety of species that differ in recreational, economic, and ecological importance. Among the most abundant taxa in the Savannah River are the gizzard and/or threadfin shad, American shad, blueback herring, sunfishes, crappie, minnows, and striped bass. American shad and striped bass are particularly important; both are anadromous species that support recreational and, in the case of American shad, commercial fisheries. The blueback herring, while somewhat less important, is another anadromous species used for commercial purposes in some coastal areas. Some species, such as the largemouth bass, while comparatively abundant as adults in the Savannah River (Paller et al. 1984, 1985), were scarce in the ichthyoplankton collections because their eggs and larvae reside in sheltered areas where they are unlikely to become entrained in currents and carried into open water. Such species are less susceptible to SRP impacts than those that produce drifting eggs and larvae.

Seasonal factors substantially influence spatial and temporal patterns of ichthyoplankton distribution in the Savannah River. Statistical analyses indicated that most of the variability in ichthyoplankton abundance observed during 1984 and 1985 was associated with sampling date, reflecting the importance of seasonal changes in temperature and photoperiod on spawning intensity (similar analyses were not performed on the 1982 and 1983 data). River level also seemed to be an important factor influencing the abundance of species such as blueback herring, minnows, and crappie which spawn most effectively in flooded areas. River level, however, had less influence on the abundance of species such as American shad and striped bass, which spawn directly in the main river channel.

The potential impacts of the SRP on the Savannah River ichthyoplankton assemblage can be categorized as follows:

1) Plume entrainment. Plume entrainment occurs when larvae drifting down the Savannah River pass through the thermal plumes leaving the mouths of Four Mile and Beaver Dam Creeks.
2) Impacts on Steel Creek. Steel Creek is one of the major tributaries in the mid-reaches of the Savannah River;

therefore, impacts on spawning in Steel Creek due to SRP operations potentially could influence the abundance of ichthyoplankton in the Savannah River.

3) Intake entrainment. Intake entrainment occurs when fish larvae and eggs are withdrawn from the Savannah River with water used to cool the SRP reactors.

Several factors mitigate the impact of plume entrainment on the Savannah River ichthyoplankton assemblage. One of the most important of these is river flooding. During flood periods, the Savannah River overflows its banks, causing the discharge from Four Mile Creek and Beaver Dam Creek to disperse and cool in the floodplain before entering the Savannah River. Since flooding generally occurs in the spring, it often coincides with major spawning periods, thus reducing the number of larvae exposed to the SRP thermal discharge. Another factor that mitigates plume entrainment is dilution of the thermal plumes with Savannah River water. Thermal-imagery studies indicate that temperatures in the Four Mile Creek plume may drop as much as 10°C within 400 m of the creek mouth due to mixing with relatively cool Savannah River water (Bristow and Doak 1983).

Investigations of ichthyoplankton distribution and abundance provided no evidence of plume entrainment impacts on the Savannah River ichthyoplankton assemblage during 1982, 1983, or 1984. The Savannah River was in flood stage during February - April 1983 and in March and May 1984, thus contributing to the lack of impact during these years. During 1985 there were indications that one species, the spotted sucker, was reduced in abundance due to passage through the Four Mile Creek plume. Two factors appeared to contribute to the apparent plume entrainment impacts observed during 1985. One was lack of flooding by the Savannah River. Lack of flooding meant that there was a thermal plume at the mouth of Four Mile Creek throughout the spawning season. The second factor was the unusual abundance of spotted sucker larvae during 1985 compared to 1983 and 1984. Spotted suckers may be more sensitive to elevated temperatures than other taxa. Thus, in years when they are more abundant, plume impacts to the taxon may be more noticeable. To put things in perspective, it is important to recognize that the plume entrainment impacts observed during 1985 were localized and species-specific. While density reductions were observed near the South Carolina bank directly downstream of the mouth of Four Mile Creek, they were not detectable farther downstream. In addition, only one species was involved. Reductions were not observed among anadromous species such as American shad and striped bass, nor among nonanadromous species such as sunfish, gizzard shad, and threadfin shad. In summary, plume entrainment does not impact the Savannah River ichthyoplankton assemblage during years when the Savannah River floods during the spawning season. During years when the Savannah River does not flood during the spawning season, sensitive taxa may experience localized impacts.

Results of the 1982-1985 studies indicate that a variety of anadromous and nonanadromous species use Steel Creek as a spawning area. Sunfishes, blueback herring, minnows, and darters were the dominant taxa during 1983 and 1984. During 1985, the ichthyoplankton assemblage in Steel Creek was largely dominated by American shad and blueback herring. Blueback herring, in particular, were abundant during all years, suggesting that Steel Creek is one of the more important spawning areas for this species in the mid-reaches of the study area. However, all the taxa collected from Steel Creek, including blueback herring, were abundant at several locations in the Savannah River and in some of the other tributary creeks under study. Blueback herring were especially abundant in the lower reaches of the study area during 1983 and 1984.

While ichthyoplankton densities were not particularly high in Steel Creek, the total number of ichthyoplankton transported into the Savannah River from Steel Creek was consistently high in relation to the other tributaries sampled during this study. During 1983, 1984 and 1985, ichthyoplankton transport from Steel Creek was higher than from any other creek in the mid- and upper portion of the study area (transport calculations were not made on the 1982 data), although there were several large creeks in the lower portion of the study area that transported more ichthyoplankton into the Savannah River than did Steel Creek. High transport from Steel Creek was primarily due to Steel Creek's large size and high discharge volume. Ichthyoplankton transport from Steel Creek raised river ichthyoplankton numbers by an estimated 10% in 1983, 13% in 1984, and 2% in 1985. All streams sampled had low transport numbers during 1985, due to low discharge and to low water levels that possibly reduced successful spawning. Some species of ichthyoplankton not transported to the river may have better survival potential in nursery areas of the swamp.

In summary, the results of this study indicate that Steel Creek is an important spawning area for both anadromous and non-anadromous species. Steel Creek probably produces more ichthyoplankton than any other Savannah River tributary in the mid- and upper reaches of the study area and contributes a significant amount of ichthyoplankton to the Savannah River. It is also important to recognize, however, that none of the ichthyoplankton taxa collected from Steel Creek were rare or endangered species and that all were found in large numbers at many locations in the river and in other tributaries.

The mechanism of intake entrainment loss at the SRP pumphouse differs for fish eggs and fish larvae. Larvae are probably killed by temperature increases and shear forces after being drawn into the reactor cooling systems. While some eggs are also destroyed in this fashion, most are probably lost as they settle to the canal bottom in the relatively quiescent canal waters. Eggs that settle out in the canals probably suffocate in the soft sediment on the canal bottom (McFarlane 1982).

A number of factors influence intake entrainment at the SRP pumphouses, including spawning in the intake canals, pumping rate, river level, ichthyoplankton density in the river, ichthyoplankton distribution in the river, and (for the 1G pumphouse) spawning in Upper Three Runs Creek. Several taxa -- most notably gizzard shad in 1982 and 1983, crappie in 1983 and 1984, and spotted suckers in 1985 -- occurred in unusually high densities in the intake canals, suggesting they were spawned there. Species that spawn in the intake canals tend to suffer increased entrainment. Similarly, when drifting eggs are more abundant in the river, there is the potential for more to be entrained, although percentage losses may remain the same. The distribution of the fish eggs in the river can also influence entrainment losses. During May 1984, American shad eggs were less abundant near the South Carolina side of the river, where the intake canals are located, thus decreasing entrainment losses for this species. Spawning in Upper Three Runs Creek can also influence entrainment losses at the 1G intake canal. High densities of blueback herring in Upper Three Runs Creek discharge increased the entrainment loss for this species during 1983. Lastly, pumping rate can have an impact, as higher pumping rates may increase water withdrawal and, consequently, ichthyoplankton entrainment. This can be especially important when river levels are low and SRP water withdrawals represent a greater proportion of the total river discharge. Water withdrawal for all pumphouses summed, expressed as a percentage of Savannah River flow, was 13.3% in 1982, 7.7% in 1983, 7.0% in 1984, and 12.2% in 1985.

The number of fish eggs and larvae lost to intake entrainment has been calculated by ECS for 1982, 1983, 1984, and 1985. McFarlane et al. (1978) calculated intake entrainment for 1978. Total estimated intake entrainment for these years (based on samples taken during daylight hours, was 26.4 million in 1977, 36.0 million in 1982, 37.2 million in 1983, 23.4 million in 1984, and 25.9 million in 1985. In 1983, 1984, and 1985, these numbers were expressed as a percentage of the total number of ichthyoplankton drifting past the intake canals; estimated entrainment was 9.3%, 8.3%, and 12.3%, respectively, of the total ichthyoplankton that drifted past the canals. These numbers are somewhat higher than the estimated 4% entrainment at the Connecticut Yankee nuclear plant on the Connecticut River (Marcy 1976) and 3.2% entrainment at the Fort Calhoun Station on the Missouri River (Hergenrader et al. 1982).

A complete assessment of intake entrainment at the SRP necessitates consideration of several mitigating factors. First, all of the species entrained at the SRP have numerous spawning sites in the Savannah River, including downstream of the SRP. Thus, at least some of their spawn is not vulnerable to intake entrainment. Second, most of the entrainment losses among the important anadromous species, striped bass and American shad, involve eggs rather than larvae. Eggs generally have a lower probability of survival than larvae. Thus, the loss of a given number of eggs is not as serious as the loss of a comparable number of larvae (Goodyear 1978). It is also important to recognize that there has been no evidence of decreasing numbers of American shad or striped bass ichthyoplankton in the Savannah River during this four-year study. In fact, the abundance of American shad eggs and larvae was much higher during 1985 than during previous years of the study. While entrainment reduces the number of American shad eggs and larvae in the Savannah River, the presence of large numbers of early life stages are suggestive of populations that are currently healthy and possibly expanding.

6.0 LITERATURE CITED

APHA. 1980. Standard methods for examination of water and wastewater. 15th ed. American Public Health Assoc. Washington, D.C.

Adams, J.G., and M.W. Street. 1969. Notes on the spawning and embryological development of blueback herring, *Alosa aestivalis* (Mitchill) in the Altamaha River, Georgia. Ga. Game Fish Comm. Atlanta, GA.

Ashley, C., P.C. Padezanin, and C.C. Zeigler. 1984. Environmental monitoring at the Savannah River Plant. Annual Report for 1983. DPSU 84-302. E.I. du Pont de Nemours & Co. Aiken, SC.

Bayless, J.D. 1968. Striped bass hatching and hybridization experiments. Proc. Ann. Conf. Southeast. Assoc. Game Fish. Comm. 21:233-244.

Breder, C.M., and D.E. Rosen. 1966. Modes of reproduction in fishes. T.F.H. Publications. Jersey City, NJ.

Bristow, J.E., and E. L. Doak. 1983. A thermal infrared survey of the Savannah River Plant, Aiken, South Carolina. DOE/ONS-8308. E.G. & G. Energy Measurements, Inc. Las Vegas, NV.

Clugston, J.P. 1973. The effects of heated effluents from a nuclear reactor on species diversity, abundance, reproduction and movement of fish. Ph.D. diss., Univ. Georgia, Athens.

Curtis, T.A. 1981. Anadromous fish survey of the Santee and Cooper River system. Ann. Prog. Rep. AFS-3-11. SCDWMRD. Columbia, SC.

DOE. 1984. Final environmental impact statement, L-Reactor Operation, Savannah River Plant, Aiken, SC. DOE/EIS-0108. U.S. Department of Energy. Washington, D.C.

Dudley, R.G., A.W. Mullis, and J.W. Terrel. 1977. Movements of adult striped bass (*Morone saxatilis*) in the Savannah River, Georgia. Trans. Am. Fish Soc. 106:314-322.

ECS. 1982. Interim report. Biological Measurement Program in the Savannah River. 1 March through 31 May 1982. DPST-82-990. Prepared for E. I. du Pont de Nemours & Company. Aiken, SC.

ECS. 1983. Final report on the preliminary biological measurement program in the Savannah River. 1 March through 31 August 1982. DPST-83-439. Prepared for E.I. du Pont de Nemours & Co. Aiken, SC.

EPA. 1976. Quality criteria for water. U.S. EPA. Washington, D.C.

Frankensteen, E.D. 1976. Genus Alosa in a channelized and unchannelized creek of the Tar River Basin, North Carolina. M.A. thesis, East Carolina Univ., Greenville, NC.

Gale, W.F., and H.W. Mohr, Jr. 1978. Larval fish drift in a large river with a comparison of sampling methods. Trans. Am. Fish. Soc. 107:46-55.

Geen, G.H., T.G. Northcote, G.F. Harman, and C.C. Lindsey. 1966. Life histories of two species of catastomid fishes in Sixteen Mile Lake, British Columbia, with particular reference to inlet stream spawning. J. Fish. Res. Bd. Can. 23:1761-1788.

Gilliland, E.R. 1983. Density and distribution of larval fish in an Oklahoma power plant cooling water reservoir. Proc. Oklahoma Acad. Sci. 63:33-36.

Goodyear, C.P. 1978. Entrainment impact estimates using the equivalent adult approach. FWS/OPS-78/65.

Goodyear, C.P. 1980. Compensation in fish populations. In: Hocutt, C., and J. Stauffer (eds.). Biological Monitoring of Fish. Lexington Books, Lexington, MA.

Grasser, L.F. 1979. Spatio-temporal distribution of clupeid larvae in Barkley Reservoir. In: D. H. Hoyt (ed.). Proc. Third Symposium on Larval Fish. Western Kentucky Univ., Bowling Green, KY.

Green, Roger H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York, NY.

Hardy, J.D., Jr. 1978. Development of Fishes of the Mid-Atlantic Bight. Vol. 3. Aphredoderidae through Rachycentridae. Biol. Serv. Prog. FWS/OBS-78/12. U.S. Dept. Int. Washington, D.C.

Hergenrader, G.L., L.G. Harrow, R.G. King, G.F. Cada, and A.B. Schlesinger. 1982. Larval fishes in the Missouri River and the effects of entrainment. In: Hesse, L.W., G.L. Hergenrader, H.S. Lewis, S.D. Reetz, and A.B. Schlesinger (eds.). The Middle Missouri River. The Missouri River Study Group. Norfolk, NE.

Hesse, L.W., Q.P. Bliss and G.J. Zuerlein. 1982. Some aspects of the ecology of adult fishes in the channelized Missouri River with special reference to the effects of two nuclear power generating stations. In: Hesse, L.W., G.L. Hergenrader, H.S. Lewis, S. D. Reetz, and A.B. Schlesinger (eds.). The Middle Missouri River. The Missouri River Study Group. Norfolk, NE.

Hocutt, C.H., J.R. Stauffer Jr., J.E. Edinger, L.W. Hall Jr., and R.P. Morgan II. 1980. Power Plants Effects on Fish and Shellfish Behavior. Academic Press, New York, N.Y.

Hogue, J.J., Jr., R. Wallus, and L.K. Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. TVA, Norris, TN.

Holland, L.E., and M.L. Huston. 1985. Distribution and food habits of young-of-the-year fishes in a backwater lake of the upper Mississippi River. J. Freshwater Ecol. 3:81-91.

Holland, L.E., and M.L. Huston. 1984. Relationship of young-of-the-year northern pike to aquatic vegetation types in backwaters of the upper Mississippi River. N. Am. J. Fish. Manage. 4:514.

Jones, P.W., F.D. Martin, and J.D. Hardy, Jr. 1978. Development of Fishes of the Mid-Atlantic Bight. Vol. 1. Acipenseridae through Ictaluridae. Biol. Serv. Prog. FWS/OBS - 78/12. U.S. Dept. Int. Washington, D.C.

Krykhtin, K.L. 1975. Causes of periodic fluctuations in the abundance of the non-anadromous fishes of the Amur Rivr. J. Ichthyol. 15:826-829.

Lathrop, B.F. 1982. Ichthyoplankton density fluctuations in the lower Susquehanna River, Pennsylvania, from 1978 through 1979. In: Bryan, C.F., J.V. Conner, and F.M. Truesdale (eds.). Fifth Annual Larval Fish Conference. Louisiana Coop. Fish. Res. Unit. Louisiana State Univ. Baton Rouge.

Leggett, W.C. 1976. The American shad (Alosa sapidissima) with special reference to its migration and population dynamics in the Connecticut River. In: Merriman, D., and L.M. Thorpe (eds.). The Connecticut River Ecological Study. Monograph No. 1. Am. Fish. Soc. Bethesda, MD.

McFarlane, R.W. 1982. The occurrence of American shad eggs in the 1G cooling water canal. DPST-82-969. Prepared for E.I. du Pont de Nemours & Co. Aiken, SC.

McFarlane, R.W., R.F. Frietsche, and R.D. Miracle. 1978. Impingement and entrainment of fishes at the Savannah River Plant: an NPDES 316(b) demonstration. U.S. DOE. Savannah River Operations Office. Aiken, SC.

Mansuetti, A.J., and J.D. Hardy, Jr. 1967. Development of Fishes of the Chesapeake Bay Region: An Atlas of Egg, Larval and Juvenile Stages. Part I. Deubler, E.E., Jr. (ed.). Nat. Resour. Inst. Univ. Maryland.

Marcy, B.C., Jr. 1976. Fishes of the lower Connecticut River and the effect of the Connecticut Yankee Plant. In: Merriman, D., and L. Thorpe (eds.). The Connecticut River Ecological Study. Monograph No. 1. Amer. Fish. Soc. Bethesda, MD.

Martin, D.B., L.J. Mengel, J.F. Novotny, and C.H. Walburg. 1981. Spring and summer water levels in a Missouri River reservoir: effects on age-0 fish and zooplankton. Trans. Amer. Fish. Soc. 110:370-381.

Merriman, D. 1950. Studies on the striped bass (Roccus saxatilus) of the Atlantic coast. Fish. Bull. Fish Wild. Serv. 50:1-77.

Merriman, D. and L.M. Thorpe (eds.). 1976. The Connecticut River Ecology Study. Monograph No. 1. Am. Fish. Soc. Bethesda, MD.

Nikolsky, G.V. 1963. The Ecology of Fishes. Academic Press. New York, NY.

NUS. 1982. Characterization of the environment at the Savannah River Plant, including Steel Creek, Savannah River swamp, and the Savannah River in the 1960s. DOE/SR-OE-5001. U.S. DOE. Savannah River Operation Office. Aiken, SC.

Odum, E.P. 1971. Fundamentals of Ecology. W.B. Saunders Co., Philadelphia, PA.

Osteen, D.V., J. O'Hara, and D. Hughes. 1984. A survey of adult fish and ichthyoplankton of the Savannah River and Augusta Canal in the vicinity of a proposed hydroelectric plant. ECS, Inc. Prepared for the City of Augusta. Augusta, GA.

Paller, M.H., J. O'Hara, and D.V. Osteen. 1985. Annual report on the Savannah River Aquatic Ecology Program. September 1983 - August 1984. Vol. II. Ichthyoplankton. ECS-SR-18. DPST-85-377. Prepared for E.I. du Pont de Nemours & Co. Aiken, SC.

Paller, M.H., J. O'Hara, D.V. Osteen, W. Specht, and H.J. Kania. 1984. Annual report on the Savannah River Aquatic Ecology Program. September 1982 - August 1983. Vol. I. ECS-SR-8. DPST-84-252. Prepared for E.I. du Pont de Nemours & Co. Aiken, SC.

Pflieger, W.L. 1975. The Fishes of Missouri. Missouri Dept. Conserv.

Robins, C.R., R.M. Bailey, C.E. Bond, J.E. Brooker, E.A. Lachner, R.M. Lea, and W.B. Scott. 1980. A list of common and scientific names of fish from the United States and Canada. 4th ed. Am. Fish. Soc. Spec. Pub. No. 12. Bethesda, MD.

SAS. 1982. SAS User's Guide: Statistics. SAS Institute. Cary, NC.

Scott, M.L., R.R. Sharitz, and L.C Lee. in press. Disturbance in a cypress-typelo wetland: an interaction between thermal loading and hydrology. Wetlands.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. J. Fish. Res. Bd. Can. Bull. No. 184.

Shines, J. E., and L. R. Tinney. 1983. A thermal infrared survey of the Savannah River Plant, Aiken, South Carolina. Winter survey. DOE/ON-8317. E. G. & G. Energy Measurements, Inc. Las Vegas, NV.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry: the Principles and Practice of Statistics in Biological Research. 2nd ed. W. H. Freeman & Co. San Francisco, CA.

Stevens, R. E. 1967. A final report on the use of hormones to ovulate striped bass, *Roccus saxatilus* (Walbaum). Proc. Ann. Conf. Southeast. Game Fish. Comm. 18:525-538.

Wang, C. S. J., and R. J. Kernehan. 1979. Fishes of the Delaware Estuaries, a guide to the early life histories. EA Communications, Ecological Analysts, Inc. Towson, MD.

Wetzel, R. G. 1983. Limnology. 2nd ed. W. B. Saunders Co., Philadelphia, PA.

Williams, R. O., and G. E. Bruger. 1972. Investigations on American shad in the St. Johns River. Florida Dept. Nat. Res. Mar. Res., Lab. Tech. Ser. No. 66.

Wrenn, W. B. 1984. Smallmouth bass reproduction in elevated temperature regimes at the species' native southern limit. Trans. Am. Fish. Soc. 113:295-303.

APPENDIX 1

Appendix 1 contains listings of computer programs that are referenced in the figures and tables of this report. This appendix is for documentation only and has not been distributed with the report.