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FOOD and FEEDING of YOUNG STRIPED BASS in ROANOKE RIVER and WESTERN ALBEMARLE SOUND, NORTH CAROLINA, 1984-1991

VOLUME I - TEXT

Completion Report for Project F-27, Striped Bass Investigations
to North Carolina Wildlife Resources Commission

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Food and Feeding of Young Striped Bass in Roanoke River and Western Albemarle Sound, North Carolina, 1984-1991

Volume I - Text

Completion Report for Project F-27
Striped Bass Investigations

For

North Carolina Wildlife Resources Commission
Archdale Building, 512 N, Salisbury Street
Raleigh, NC 27611

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EXECUTIVE SUMMARY

This study was conducted during the period 1987-1991 to examine several possible causes of the decline in the Roanoke/Albemarle striped bass stock. The species supports multi-million dollar sport and commercial fisheries in northeastern North Carolina; since 1977 the population has declined steadily. Striped bass in this system migrate about 130 miles upstream in the spring (April through June) to spawn in the main channel of the Roanoke River. This location is the primary and only spawning ground documented for this stock. A number of environmental factors have been suggested as potential contributors to the decline: channelization, dredge and fill projects, dams and impoundments, industrial water intakes and discharges, chemical pollution, turbidity, low oxygen levels, sewage outfalls, poor timing of water release from reservoirs upstream, reduced spawning habitat, reduced nursery habitat, poor food availability, generally poor water quality, and spawning grounds too accessible to fishermen. All these environmental factors in combination may cause a number of biological problems for striped bass such as reduced egg viability, poor survival of larvae during downstream drift from spawning grounds to nursery areas, and poor survival of juveniles on the nursery grounds.

The goal of the study was to characterize the food web for larval striped bass in the lower Roanoke River and western Albemarle Sound, North Carolina, to ascertain if poor juvenile recruitment is a result of food chain interruption. Objectives were: 1) to determine the relative abundance and distribution of striped bass post-hatch life stages in the study area; 2) to determine the location in the River where larval feeding is first observed; 3) to determine the density and relative abundance of potential prey (zooplankton), and identify those organisms selected as food by larval striped bass; 4) to determine the density and species composition of phytoplankton algae available to support zooplankton production; 5) to determine the relationships existing among phytoplankton, zooplankton, and young striped bass; and 6) to determine the utilization of emergent aquatic vegetated areas by striped bass young. We combined data sets on water quality, primary productivity, zooplankton, larval abundance, and larval food habits with data collected from a previous study (1984-1986) to provide information spanning eight years of varying seasonal weather and river flow patterns.

River Flow. Both low and high extremes in Roanoke River instream flow were observed during the April-June period, 1984-1991. The mean instream flow for April-June 1985 was the lowest in the 80 years of record keeping, and drought conditions prevailed in 1986. Flooding during the spring of 1987 resulted in the mean April-June river flow to be the highest on record. Starting in 1988, the manner in which reservoir waters from the Roanoke Rapids Dam at River Mile 137 (just above the spawning grounds) was changed to reduce sudden changes in instream flow (1,500 cubic feet per second per hour, rather than doubling or halving the release rate). Seasonal mean flow rates were moderate in 1988 and 1991, and high in 1984 and 1989.

Water Quality. Generally, water temperatures were warmer in Batchelor Bay and western Albemarle Sound than those measured at the same time in the lower River and Delta. Dissolved oxygen levels usually remained above 4 mg/L every spring, except during high river flow periods in 1987 and 1989. Surface water pH remained at or above 7.0 for years 1988-1991; in 1986, waters were acidic for most of the spring. The lower River and western Sound were oligohaline during the April-June period; salinities ranged from 0.0 to 0.4 ppt. Special chemical monitoring studies were conducted just below the spawning grounds and at several locations in the Roanoke River Delta in 1988 and 1990. At both sites, total suspended solids and heavy metals, including aluminum, calcium, iron, potassium, manganese, magnesium, sodium, and zinc were higher in the lower flow conditions of 1988. Increased alkalinity, nitrate-nitrite, and sulfate were observed in the higher flows of 1990 at both upstream and Delta locations.

Phytoplankton and Chlorophyll *a*. Chlorophyll *a* data show a clear inverse relationship with Roanoke River flow. During each spring, 1984-1991, chlorophyll *a* levels generally were less than 10 µg/L in the study area, usually between 4 and 7 µg/L and rarely more than 15 µg/L. A total of 154 phytoplankton species was found in the 1984-1991 samples. Phytoplankton was dominated by green algae and diatoms. Most phytoplankton cell types occurred infrequently, but several were very common. Blue-green algae, if present, never represented more than two percent of total phytoplankton density, which averaged in the range of 500-3,000 cells/ml. Densities were highest early in the sampling period and tended to decline with early summer. Both phytoplankton density and biomass were considerably lower in Batchelor Bay than in the River.

Zooplankton. The abundance of zooplankton in the lower River, Bay, and western Sound was less than for other river systems supporting spawning populations of striped bass. Zooplankton densities commonly averaged between 600 and 1000 individuals/m^3. Zooplankton abundance was not uniform throughout the watershed, but typically was concentrated in several areas: the lower Cashie River, lower Middle River, and the Roanoke River main stem near its discharge into Batchelor Bay. In the Bay, zooplankton were higher on average along the western shore, and in Albemarle Sound zooplankton were more dense along the north shore near Edenton Bay. In general the zooplankton of this system resembled a freshwater assemblage of taxa, but the community changed from the River through the Bay and into the Sound. The River zooplankton communties were dominated by cladocerans, especially *Daphnia* and *Bosmina*, and copepods (primarily cyclopoids). Batchelor Bay was a region of transition for the zooplankton community. Cladocerans still dominated but copepods increased in importance. In the western Sound, copepods became dominant with cladocerans second in abundance. In all, 10 unique zooplankton communities were identified within the study area. Daily and prevailing seasonal River flows altered the relative abundance and composition of these communities. Zooplankton did not appear to be phytoplankton limited, so environmental factors such as river flow may have been responsible for the continually low zooplankton abundance.

Eggs. Striped bass eggs were collected in the lower Roanoke River in every year except the flood year of 1987. Highest egg densities were always upstream between Hamilton and

Williamston, North Carolina. No eggs were collected from either the Middle or Cashie rivers except in 1990. In contrast, white perch eggs were collected at many River and Delta stations during the eight-year study, except for 1987 when no white perch eggs were collected.

Larval Striped Bass Abundance. Peaks in larval striped bass densities always occurred in May, but the timing and pattern of abundance was directly related to spawning activity upstream. Highest average densities were recorded in 1988, a moderate flow year. Second highest densities occurred in 1985 and 1986; low flows in these years may have resulted in larvae remaining within the lower reaches of the watershed rather than being transported to western Sound nursery grounds. Lowest densities were observed in high flow years. Most striped bass larvae were within a size range of 4.5-7.0 mm total length. White perch larvae were smaller than striped bass. Larvae in the Bay and Sound were usually slightly larger than their counterparts in River habitats.

First Feeding of Larvae. The location in the River at which larval feeding first occurs is not a direct function of transport time downstream *per se*, but rather the fortuitous interaction of growth rate and their location in the river when the fish achieves function of the developing mouth parts. Growth rate is a function of water temperature and, to a lesser extent, dissolved oxygen, pH, and other environmental factors. First observations of successful feeding were in the lowest sections of the Roanoke River and its distributaries, and Batchelor Bay rather than upstream as was hypothesized in the early years of the study. However, larvae capable of feeding were collected in the upstream stations. Stage 1 striped bass larvae (those with yolk) fed successfully in the lower River and Delta in low and moderate flow years, but apparently do not feed successfully in those areas in high flow years. Stage 2 larvae (no yolk) apparently can feed successfully in most Delta areas early in the season, but high flows move successful feeding larvae out into western Albemarle Sound. By comparison, white perch larvae fed successfully early in the season and at most River stations including those upstream.

Larval Feeding Frequency. More larval striped bass from Batchelor Bay and the western Sound contained prey in stomachs compared to those from the River and Delta. One possible explanation is that larvae in the Bay and Sound were slightly larger and therefore should be foraging more effectively; however, this hypothesis was not always the case. The few white perch larvae examined in 1988 and 1991 had greater feeding success than larval striped bass collected in the same area.

Zooplankters as Prey. *Bosmina* was the zooplankton prey consumed most often by larval striped bass in the lower Roanoke River and Delta. In Batchelor Bay (the transitional zooplankton community), prey selection seemed to be influenced by seasonal river flow patterns. In low flow years, copepodid (juvenile) copepods were the major food; in moderate and high flow years *Bosmina* was the dominant prey. In western Albemarle Sound, copepodids were the major food in all years. By comparison, white perch larvae had a more diverse diet in the River, but in the Bay and western Sound food habits were similar to striped bass larvae. An electivity index, which relates the proportion of prey items eaten to the proportion in the zooplankton, showed that striped bass larvae prefer *Bosmina* in the Delta, and copepodid copepods in the Bay and western Sound. Adult copepods and *Daphnia* were not consumed at a rate commensurate with their relative contribution to the zooplankton. This indicates that the prey were not selected for, or were inaccessible (e.g., too large to ingest). White perch had negative values for *Bosmina, Daphnia*, and adult copepods. White perch larvae are smaller than striped bass larvae, and may have a smaller mouth gape thus limiting prey to smaller sizes.

We conclude that one factor influencing the number of Roanoke striped bass larvae recruiting successfully to the forming year class in Albemarle Sound is the match/mismatch phenomenon driven by seasonal and daily patterns in instream flow. Seasonally moderate instream flow patterns position the larvae lower in the River and Delta where zooplankton densities are greatest, and then gradually carry them to the western Sound nurseries. Low flows cannot provide the current needed by larvae to move them into Batchelor Bay and the Sound in a timely fashion, and high flows flush both zooplankton and larvae out of the Delta before feeding is initiated. The low zooplankton concentrations observed in this system do not mean that successful year classes are not possible: in years of high larval production, more young will survive regardless of food supply in the river. However, larval survival would be enhanced if habitat conditions, such as an adequate food supply, were optimal.

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INTRODUCTION

A variety of estuarine-dependent fish species inhabiting Albemarle Sound and its tributaries support important commercial and recreational fisheries in coastal North Carolina. Of those species, striped bass (*Morone saxatilis*) has been one of the most important. A major portion of fishery research efforts in Albemarle Sound waters since 1955 has focused on striped bass, which constitutes a multi-million dollar fishery in the region (Rulifson et al. 1982a).

For several hundred years the striped bass fishery in the Roanoke River and Albemarle Sound has been an important component of the lives of coastal residents as a source of income, sport and social interaction. The major spawning area for Albemarle Sound striped bass is located in the Roanoke River, a swiftly-flowing coastal stream that empties into the extreme western end of the Sound (Figure 1). Spawning occurs upstream between Halifax (River Mile 120) and Weldon (RM 130), North Carolina, from late April through early June (Hassler et al. 1981). The historical spawning grounds further upstream were blocked by construction of the Roanoke Rapids Dam at RM 137 (McCoy 1959). Eggs develop to the hatching stage as they are transported downstream by currents. After hatching, the larvae are transported downstream through the Roanoke River delta and into western Albemarle Sound to the historical nursery areas (Rulifson et al. 1988).

In recent years, the striped bass fishery in this area has suffered from reduced numbers of harvestable adults. The Albemarle Sound stock has been in decline for over a decade; a strong year class of Roanoke striped bass has not been observed since 1970, and no significant year classes have been produced since 1976 (Hassler et al. 1981; USDOI and USDOC 1985). Research conducted in Chesapeake Bay suggests that striped bass must have a strong, successful year class at least every six years in order to maintain and preserve stock size. For a number of years, the Albemarle striped bass population has been stocked with hatchery-reared fish on a routine basis by federal and state fishery agencies in an attempt to maintain stock size until causes for the decline are determined.

Since the late 1970s, scientists have examined several factors that may contribute to the decline of the Roanoke stock. State and federal fishery personnel believe that a number of environmental factors may be important contributors to stock decline within the Roanoke River: channelization, dredge and fill projects, dams and impoundments, industrial water intakes and discharges, chemical pollution, turbidity, low oxygen levels, sewerage outfalls, poor timing of water release from dams, reduced spawning habitat, reduced nursery habitat, poor food availability, spawning grounds too accessible to fishermen, and generally poor water quality (Rulifson et al. 1982b). Within Albemarle Sound, low oxygen levels and high water temperatures combined with generally poor water quality are suspected (Rulifson et al. 1982b), perhaps causing a phenomenon known as "habitat squeeze" (Coutant 1985, 1990). All of these environmental factors may cause a number of biological problems for striped bass such as reduced egg viability (Guier et al. 1980, Hassler et al. 1981), poor survival of larvae during downstream drift from spawning grounds to nursery areas (Rulifson 1984a; Rulifson and Stanley

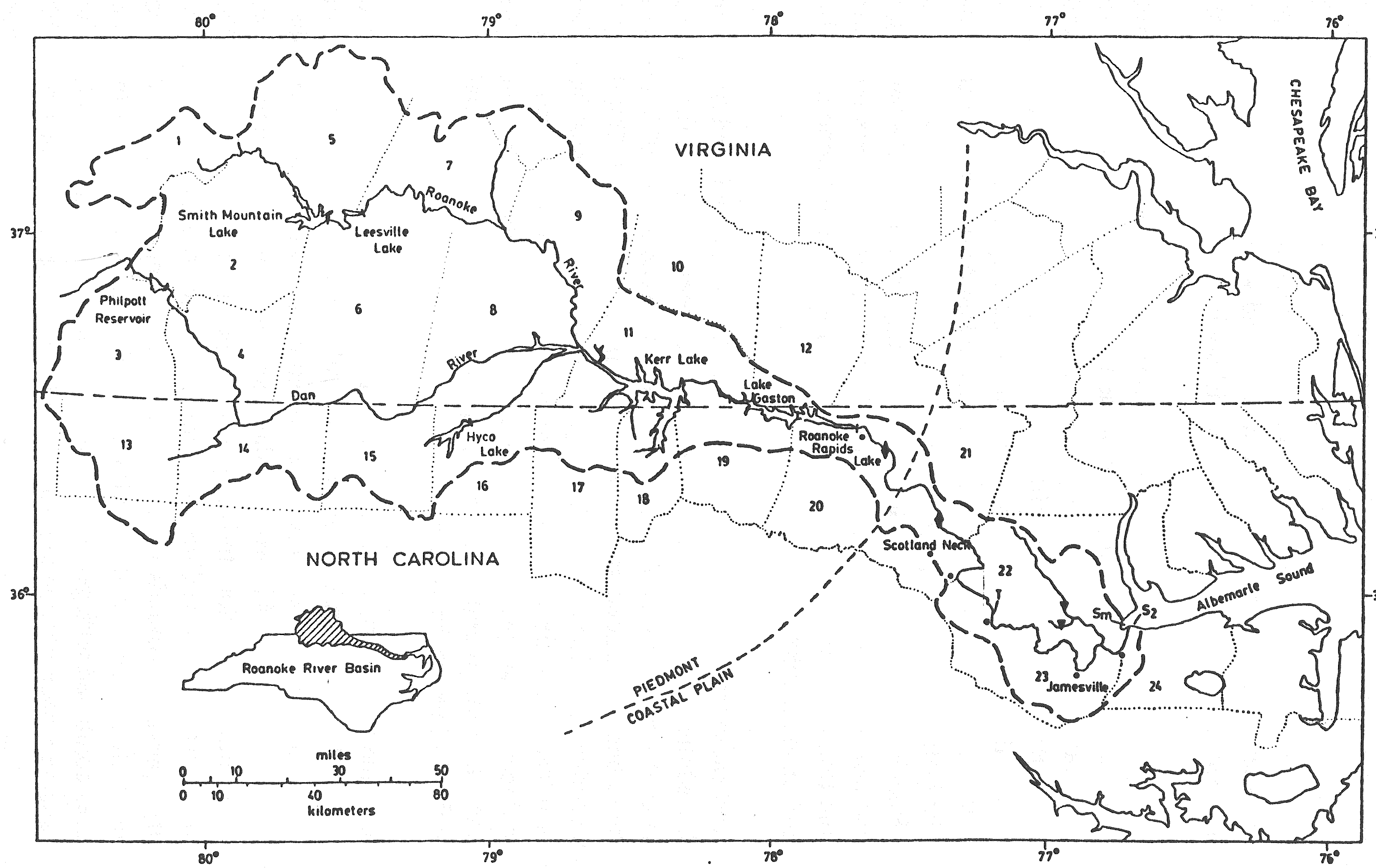


Figure 1. Drainage area of the Roanoke River Basin (from Manooch and Rulifson 1989).

1985; Rulifson et al. 1986a, 1986b), and poor survival of juveniles on the nursery grounds (Hassler et al. 1981). Estimates of the number of eggs spawned each year in the Roanoke River indicate that adequate numbers of eggs and larvae are produced to maintain population levels (Kornegay 1981, Kornegay and Mullis 1984). However, surveys of larvae and early juveniles in nursery areas of the western Sound indicate low recruitment of these life stages. Results of these studies suggest that excessive mortality occurs between hatching and juvenile life stages, probably in the lower Roanoke River and delta (Rulifson et al. 1986a; 1986b).

Starvation has been hypothesized as one of the principal causes of larval Roanoke striped bass mortality (Rulifson 1984; Rulifson and Stanley 1985; Rulifson et al. 1986a, 1986b), and is hypothesized as one of the contributors to poor year classes of Potomac striped bass between 1974 and 1977 (Martin and Malloy 1981). Striped bass larvae appear to be food limited in the Roanoke River system in years of high flow and extremely low flow (Rulifson et al. 1986a). High river flow, caused by freshwater discharge from Roanoke Rapids Lake, sweeps striped bass eggs and yolk-sac larvae into areas of extremely poor zooplankton productivity in western Albemarle Sound (Rulifson and Stanley 1985). Low flow conditions allow greater zooplankton productivity in the lower Roanoke River, but not in concentrations great enough for the larvae to feed successfully (Rulifson et al. 1986a). Poor water quality or the presence of pollutants, possibly causing aberrant feeding behavior of the larvae and resulting in starvation, has been hypothesized also (Rulifson 1984a).

Zooplankton surveys conducted in western Albemarle Sound in 1982 and 1983 (Rulifson 1984a), and in the lower portions of the Roanoke watershed in 1984 and 1985 (Rulifson et al. 1986a), indicated zooplankton densities of one to two orders of magnitude less than other estuarine waters containing striped bass stocks (e.g., Potomac River Estuary; Sacramento-San Joaquin Estuary). These data suggest that poor survival of striped bass postlarvae and smallest juveniles may be caused in part by an inadequate food supply.

Inadequate food supply is not simply a function of numbers of prey items, but also the quality of the prey. Zooplankton must be of the right size and speed to be caught and ingested by larval fish. In other words, prey supply is the combination of prey abundance and prey accessibility (Ney 1990, Brandt et al. 1992). Local density-dependent (biological) and density-independent (physical) processes on a small scale can greatly affect trophic interactions, mortality, and eventually production at the system level (Kareiva and Andersen 1988, Possingham and Roughgarden 1990, Brandt et al. 1992).

The goal of the study described herein was to characterize the food web for larval striped bass in the lower Roanoke River and western Albemarle Sound, North Carolina, to ascertain if poor recruitment is a function of food chain interruption. Several objectives were used to achieve this goal: 1) to determine the relative abundance and distribution of striped bass post-hatch life stages in the study area; 2) to determine the location in the river where feeding of yolk-sac larvae is first initiated, relative to river flow; 3) to determine the density and abundance of potential prey (zooplankton) and identify those organisms selected as food by larval striped bass;

4) to determine the density and species composition of phytoplankton algae available to support zooplankton production; 5) to determine the relationships existing among phytoplankton, zooplankton, and young striped bass; and 6) to determine the utilization of emergent aquatic vegetated areas by striped bass young. Results of portions of these and related studies were documented by Rulifson (1984a, 1984b, 1989, 1990), Rulifson and Stanley (1985), Rulifson et al. (1986a, 1986b, 1988), Manooch and Rulifson (1989), and Rulifson and Manooch (1990a, 1990b, 1991).

Although the reporting period for the work is 1987-1991, all data bases starting in 1984 have been included so that long-term trends in data sets, as influenced by numerous environmental parameters, can be described. One of the most important environmental components is river flow. At the present time, U.S. Geological Survey personnel (Bales et al.) are in the process of decribing flow patterns of the lower Roanoke River and western Albemarle Sound using mathematical models. Their studies are not complete at this time, so we have used the flow records from the USGS (U.S. Geological Survey) gage at Roanoke Rapids. Complete data sets for water quality, chlorophyll, phytoplankton, zooplankton, and larval fish are presented in Volume II of this report so that the information is readily usable for transport modelling studies.

STUDY SITE DESCRIPTION

The Roanoke River and surrounding lands form an extensive bottomland hardwood floodplain in northeastern North Carolina. From its headwaters in the Blue Ridge mountains of Virginia, the Roanoke River drains 25,035 km^2 in Virginia and North Carolina, where it discharges into the extreme western end of Albemarle Sound (Figure 1) making it the largest basin of any North Carolina estuary (Giese et al. 1985). Between 1950 and 1963, a series of dams was established near the North Carolina-Virginia border for hydroelectric power and flood control. The most upstream of these impoundments is John H. Kerr Reservoir at River Mile (RM) 179, which is maintained by the U.S. Army Corps of Engineers (Corps) for flood control, hydroelectric production, and recreation. Kerr Dam was completed in 1952; its closure resulted in the landlocking of a portion of the Roanoke striped bass population which spawned in several tributary rivers upstream. Construction of Roanoke Rapids Dam (the most downstream facility) at RM 137 in 1955 blocked access to the remaining spawning grounds (McCoy 1959). Gaston Dam, located between Kerr and Roanoke Rapids dams, was completed in 1963. Both Gaston and Roanoke Rapids are maintained by Virginia Power Company for electric power production. Of these facilities, Kerr Reservoir is the most important to the lower river and Albemarle Sound because of its storage capacity and direct influence on the operation of the two hydroelectric dams downstream. With an annual average discharge of 8,900 cfs (cubic feet per second) at the mouth (252 m^3/second, or 0.01 m^3/second/km^2), the Roanoke River is the second largest estuary and contributes about 50% of the freshwater input to Albemarle Sound (Giese et al. 1985).

Precipitation is the primary source of water input to the lower Roanoke River basin. Hydrological data for the lower Roanoke River basin were summarized by the U.S. Army Corps of Engineers (1968, 1984). Precipitation within the lower basin averages from 41 to 53 inches per year, depending on location. Snowfall within the basin ranges from 3 to 10 inches. Widespread precipitation throughout the entire watershed causes increased discharge of mainstream tributaries. Localized rainfall events usually cause increased discharge only in smaller tributaries.

The Coastal Plain portion of the Roanoke River was once a drowned river valley but now is filled with sediments (Giese et al. 1985, Riggs et al. 1991). The greatest width of the estuary (0.3 miles) is near the mouth. Upstream from Plymouth, North Carolina, the width is commonly less than 0.1 mile. Heavy sedimentation from upstream formed a delta of unusual configuration. There are three main distributaries: the Cashie River, Middle and Eastmost Rivers, and the Roanoke River estuary (Figure 2). Water depth in the river averages from 4.6 to 8.7 m. Within the delta, water depth changes rapidly: mudbanks may extend several meters from shore to terminate in dropoffs over 24 m deep. A navigation channel is maintained in the main Roanoke River from Albemarle Sound to Palmyra (RM 81), North Carolina. Channel dimensions are 45.7-m wide by 3.6-m deep from the river mouth to Plymouth, and 24.4-m wide by 2.4-m deep from Plymouth to Palmyra (Giese et al. 1985). Bottom sediments are an orange inorganic clay overlying medium to coarse sands fining upwards to fine sands, muds, or peats (Riggs et al. 1991). Vegetated areas have become established on shallow and shoreline mud deposits accumulated as a result of river impoundment.

The coastal portion of the Roanoke River downstream of Roanoke Rapids Dam is classified as a "C" stream by the North Carolina Division of Environmental Management (DEM). The river receives wastes from a number of municipal and industrial sources in addition to agricultural runoff. Permitted discharges to the river are regulated by the National Pollution Discharge Elimination System (NPDES) based primarily on the volume of wastewater measured in millions of gallons per day (MGD) and on the biochemical oxygen demand (BOD) in mg/L and/or pounds per day (Table 1). The DEM has assigned a "water quality limited" category to the Roanoke River near Plymouth (approximately RM 5) because of observed dissolved oxygen levels below the 5.0 mg/L limit established by the U.S. Environmental Protection Agency (USEPA, Appendix Table A-1).

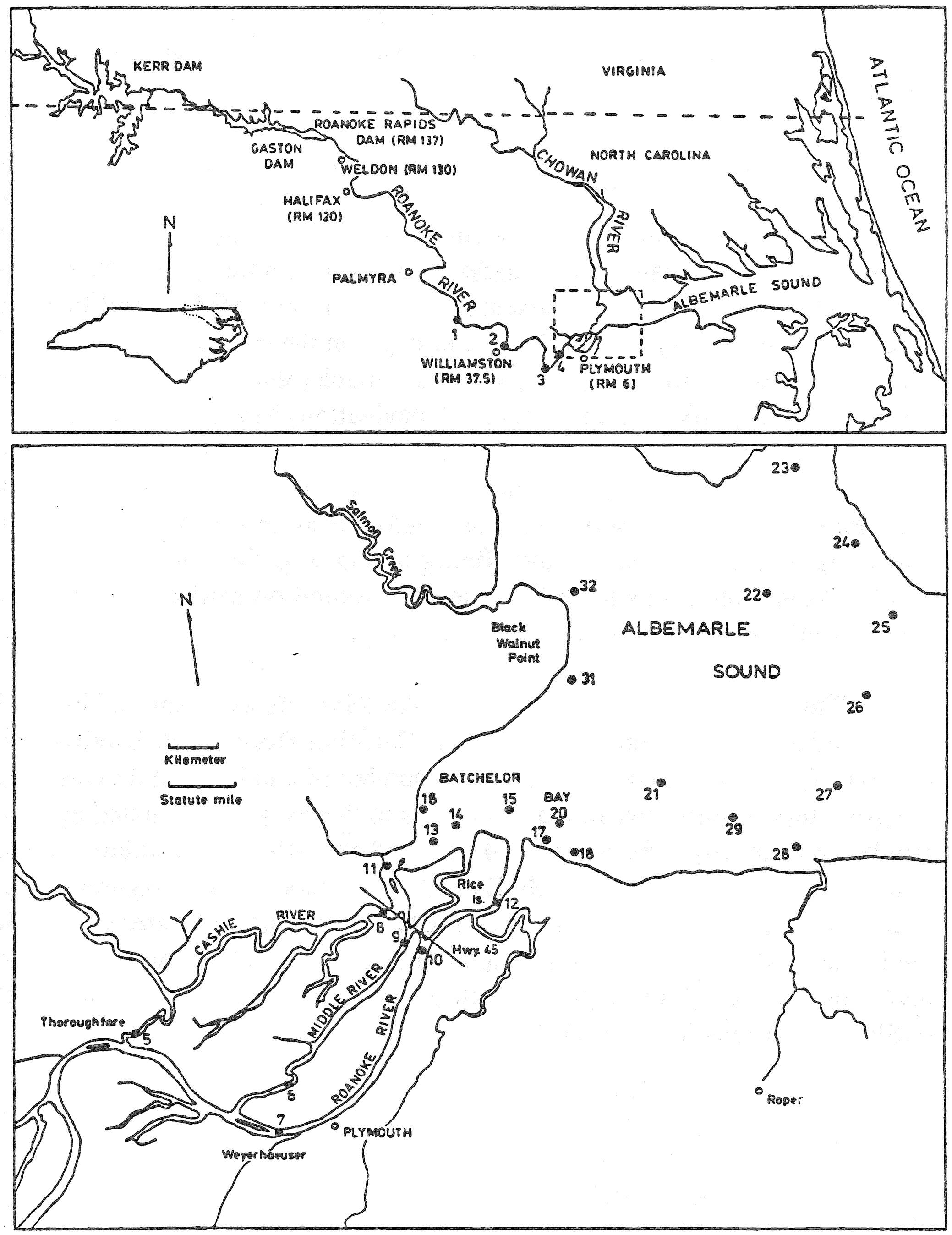


Figure 2. Map depicting the locations of sampling sites used during the period 1984-1991. Not all sites were sampled each year.

Table 1. **NPDES dischargers to the lower Roanoke River Basin.**

Discharger	Permitted Waste Volume (mgd)	Permitted BOD concentration mg/L		Maximum BOD Loading (lbs/d)		Approximate Location (River Mile)
		Summer (Apr - Oct)	Winter (Nov - Mar)	Summer	Winter	
Champion International Paper Company Mill	28.00	lbs/d	lbs/d	6,850	6,850	137.0
Roanoke Rapids Sanitary Dist.	8.34	30.0	30.0	2,090	2,090	133.5
Weldon Wastewater Treatment Plant	0.12	15.0	15.0	150	150	131.5
N.C. Department of Corrections, Odom	0.08	30.0	30.0	20	20	111.5
N.C. Department of Corrections, Caledonia	0.80	5.2	10.4	35	70	107.0
Rich Square Wastewater Treatment Plant	0.30	30.0	30.0	75	75	102.5
Perdue Farms	3.00	lbs/d	lbs/d	814	814	93.0
Hamilton Wastewater Treatment Plant	0.08	30.0	30.0	20	20	61.3
West Point-Pepperell	1.50	lbs/d	lbs/d	179	179	---
Williamston Wastewater Treatment Plant	2.00	30.0	30.0	501	501	37.0
Liberty Fabrics	0.45	lbs/d	lbs/d	125	125	29.0
Jamesville Wastewater Treatment Plant	2.00	30.0	30.0	38	38	18.0
Weyerhaeuser Company Mill	55.00	lbs/d	lbs/d	9,340	18,680	8.0
Plymouth Wastewater Treatment Plant	0.80	19.0	30.0	126	201	5.0
<u>Cashie Subbasin</u>						
Lewiston-Woodville Wastewater Treatment Plant	0.15	30.0	30.0	38	38	---
Windsor Wastewater Treatment Plant	1.15	10.0	16.0	96	154	---

METHODS

Sample Collection

Sampling for phytoplankton, zooplankton, and ichthyoplankton in the lower Roanoke River, delta (Roanoke, Middle, and Cashie rivers), and western Albemarle Sound was conducted each spring from 1984 through 1991. Exact sampling dates and stations selected for sampling changed each year depending on striped bass spawning activity, local weather patterns, and results of the study from the previous year. A total of 29 fixed sampling sites in the lower river, delta, and western Albemarle Sound have been used at various times since 1984 (Figure 2). Not all stations were sampled in all years. Table 2 provides a description of each location and the years for which each station was sampled.

Several vessels were used to collect the samples during the eight-year study. Stations 1, 2, 3, and 4, located between Hamilton and just upstream of the delta, were sampled each year by personnel of the North Carolina Wildlife Resources Commission (WRC). From 1984-1987, the vessel was a 15-ft fiberglass open boat with center console (Boston Whaler) outfitted with a steel boom and block and powered by an 85-hp outboard motor. In 1988, the vessel was a similarly-constructed 18-ft boat (Sou'Wester) powered by a 100-hp outboard motor. Station 5, located in the upstream portion of the Thoroughfare, also was sampled by WRC personnel for the first half of the season and later sampled by Institute personnel. The remainder of the stations (Table 2) was sampled by Institute personnel. In 1984 and 1985, samples were taken using the *Pirate's Pride*, a 26-ft open fiberglass flat-bottomed boat with forward cabin powered by a 235-hp outboard motor mounted in a well near the stern. Zooplankton and ichthyoplankton nets were deployed from a galvanized steel "goalpost" structure mounted at the stern. For the period 1986-1991, sampling was conducted using the *Serrana*, a 22-ft fiberlass semi-displacement hulled boat with cabin powered by a 225-hp V8 inboard engine turning a 16-in x 13-in propeller with a 1.52:1 gear ratio.

Water Quality

Routine Data. Environmental conditions were recorded at selected stations each year of the study. Water temperature (°C) was measured *in situ* with a YSI oxygen meter (Model 58B) or with a Beckman electrodeless induction salinometer. Both meters were compared to and calibrated with a certified Fisher thermometer. Dissolved oxygen (mg/L) was measured with a YSI oxygen meter (Model 58B) *in situ*, which was calibrated prior to each trip to ambient conditions based on the manufacturer's recommendations. The YSI meter was checked periodically by the Winkler method. The backup field method was the Winkler method, for which the dissolved oxygen was fixed onboard the vessel and then returned to the laboratory for completion of the test. Conductivity (mhos) was measured with the Beckman salinometer calibrated to manufacturer's specifications. The backup field method was a Corning PS17 conductivity meter calibrated to the Beckman meter. *In situ* pH was determined with a Corning PS15 pH meter calibrated before each sample by immersing the electrode in a Fisher 7.0 pH

Table 2. Descriptions of the fixed sampling locations used in the striped bass food and feeding study, 1984-1991. Descriptions are facing downstream; i.e., right bank = south or Plymouth side. RM = river mile. Refer to Figure 2 for graphical information.

Station number	Approximate latitude/ longitude	Physical description	Years sampled
1	35:51:00N, 77:02:30W (RM 37)	Williamston - Roanoke R. mainstem; strong currents; steep banks; little submerged or emergent vegetation; soft bottom covered with thick layers of pine bark.	1984-1988
1	35:57:00N, 77:02:30W (RM 57)	Hamilton - Roanoke R. mainstem; strong currents; steep banks; little submerged or emergent vegetation; soft bottom covered with thick layers of pine bark.	1989-1991
2	35:48:15N, 76:53:45W (RM 19)	Jamesville - similar to Station 1	1984-1988
2	35:51:00N, 77:02:30W (RM 37)	Williamston - the former Station 1 (1984-88)	1989-1991
3	35:48:15N, 76:53:45W (RM 19)	Jamesville - the former Station 2 (1984-88)	1989-1991
4	35:50:00N, 76:51:45W (RM 16)	Power lines - similar to Station 1; several "snags"	1984-1991
5	35:56:36N, 76:48:11W	In the uppermost Thoroughfare about 0.5 RM downstream of its exit from the Roanoke River; mean depth 5.6 m, maximum 7.6 m.	1984-1991
6	35:53:22N, 76:45:06W	In the uppermost Middle River about 0.5 RM downstream of its exit from the Roanoke River; mean depth 5.1 m, maximum 12.2 m.	1984-1991
7	35:52:45N, 76:45:16W (RM 7.5)	Roanoke River mainstem adjacent to Weyerhaeuser and just above Welch Creek and the diffuser pipe; moderate currents; steep banks and deep on right shore (Plymouth) gradating to extensive shallow, narrow channel, sides covered with emergent lily pads on left shore; mean depth 6.8 m, maximum 9.8 m.	1984-1991

Table 2 continued.

Station number	Approximate latitude/ longitude	Physical description	Years sampled
8	35:56:27N, 76:43:24W	Cashie River just upstream of N.C. Highway 45 bridge; moderate currents; steep bank and deep water on left side gradating to extensive shallow, unnavigable shelf with emergent lily pads on right shore; mud bottom; mean depth 6.9 m, maximum 12.2 m.	1984-1991
9	35:56:01N, 76:42:58W	Middle River just upstream of the N.C. Highway 45 bridge; moderate currents; straight and fairly uniform section of river; mean depth 5.1 m, maximum 18.3 m in the river bend just downstream.	1984-1991
10	35:55:45N, 76:42:36W (RM 3)	Roanoke River main stem about 500 m upstream of the N.C. Highway 45 bridge; fairly wide and shallow; bottom more sandy than mud; mean depth 4.3 m, maximum 6.1 m.	1984-1991
11	35:57:07N, 76:43:22W	Cashie River mouth downstream of N.C. Highway 45 bridge just upstream of Batchelor Bay; deep water on left bank gradating to shallow waters and islands on right bank; mean depth 7.3 m, maximum 10.7 m.	1984-1991
12	35:56:47N, 76:41:06W (RM 1)	Near the Roanoke River mouth about 600 m downstream of its confluence with Canaby Creek and upstream of navigation marker R12; shelf with lily pads on left and right banks; mean depth 6.3 m, maximum 8.5 m.	1984-1991
13	35:57:18N, 76:43:00W	Batchelor Bay just seaward of the Cashie River discharge into western Albemarle Sound; mean depth 1.8 m, maximum 4.6 m; numerous submerged and floating snags; hard sand bottom littered with leaves and detritus.	1984-1991
14	35:57:50N, 76:42:02W	Batchelor Bay just seaward of the Eastmost River discharge into western Albemarle Sound; similar to Station 13; mean depth 2.4 m, maximum 3.0 m.	1984-1986
15	35:57:31N, 76:41:16W	Batchelor Bay just seaward of the Roanoke River discharge into western Albemarle Sound; Similar to Station 13; mean depth 2.5 m, maximum 4.6 m.	1984-1991
16	35:57:34N, 76:42:47W	Southwest shore of Batchelor Bay just north of Cashie River mouth; Similar to Station 13; mean depth 1.9 m, maximum 3.0 m.	1984, 1985, 1987-1990

Table 2 continued.

Station number	Approximate latitude/ longitude	Physical description	Years sampled
17	35:56:59N, 76:41:00W	South shore of Albemarle Sound just east of Roanoke River mouth; uniform shallow depth; numerous snags. mean depth 2.9 m, maximum 3.7 m.	1984, 1987
18	35:56:36N, 76:39:39W	South shore of Albemarle Sound about 1 km east of Roanoke River mouth; mean depth 2.4 m, maximum 3.1 m.	1984, 1987-1991
20	35:57:18N, 76:41:05W	Southwest Albemarle Sound about 0.75 km from Roanoke River mouth; mean depth 3.1 m, maximum 4.3 m.	1986-1991
21	35:57:05N, 76:39:20W	Southwest Albmarle Sound at navigation buoy 1 (4-second flashing green); about 3 km NE of the Roanoke River mouth; reduced currents, varies with river discharge and prevailing winds; mean depth 3.8 m, maximum 5.2 m; hard sand bottom with some submerged snags.	1986-1991
22	36:00:28N, 76:37:02W	Northwest Albemarle Sound at Buoy AS (Morse Code A) about 7.5 km from mouth of Roanoke River; mean depth 5.0 m, maximum 6.4 m; hard sand bottom; probably influenced by Chowan River discharge.	1986-1991
23	36:02:06N, 76:36:07W	Edenton Bay in northwest Albemarle Sound about 10 km from Roanoke River mouth; usually some salinity (0.2-0.5 ppt); probably influenced by Roanoke River discharge only in high flow years; mean depth 4.5 m, maximum 5.2 m.	1986-1991
24	36:01:25N, 76:35:35W	Northwest Albemarle Sound; mean depth 4.3 m, maximum 5.5 m.	1986-1991
25	35:59:29N, 76:35:12W	North shore of western Albemarle Sound near the old Norfolk and Southern Railroad bridge; mean depth 6.4 m, maximum 6.7 m.	1986
26	35:58:22N, 76:35:22W	Central western Albemarle Sound about mid-way along the old Norfolk and Southern Railroad bridge; mean depth 5.0 m, maximum 6.1 m.	1986-1991
27	35:58:08N, 76:35:32W	South side of western Albemarle Sound along the old Norfolk and Southern Railroad bridge; mean depth 5.3 m, maximum 6.1 m.	1986

Table 2 continued.

Station number	Approximate latitude/ longitude	Physical description	Years sampled
28	35:56:35N, 76:36:01W	South shore of western Albemarle Sound near Mackey's Landing; about 6 km east of the Roanoke River mouth; mean depth 3.8 m, maximum 5.2 m.	1986-1991
29	35:57:46N, 76:37:25W	South western Albemarle Sound about 4.5 km from the Roanoke River mouth; mean depth 4.7 m, maximum 4.9 m.	1986
31	36:00:24N, 76:39:45W	Western shore of western Albemarle Sound near Black Walnut Point; about 4 km from Roanoke River mouth; historical nursery grounds for YOY striped bass; mean depth 3.2 m, maximum 4.7 m.	1987-1991
32	35:58:38N, 76:40:36W	Western shore of western Albemarle Sound at Black Walnut Point and mouth of the Chowan River; offshore of the mouth of Salmon Creek; historical nursery grounds for YOY striped bass; mean depth 3.8 m, maximum 4.6 m.	1987-1991

solution. The backup meter was a Fisher pH pen. Turbidity was measured with a HF Instruments DRT15 turbidity meter using USEPA standards for comparison. Cloud cover was estimated visually as percentage of the sky that contained clouds. Wind direction was recorded as the compass bearing from which the local wind originated (NE=1; E=2; SE=3; S=4; SW=5; W=6; NW=7; N=8; no wind = 0). Wind velocity (mph) was estimated using a hand-held wind velocity meter. Water depth (m) was measured electronically with a hull-mounted depth recorder.

Special Water Quality Studies. Additional water quality studies were conducted in 1988 and 1989 to monitor nutrient and heavy metal concentrations within the lower Roanoke River during striped bass spawning activity. Details of the 1988 study were described by Rulifson et al. (1990). Briefly, whole water samples were collected at four stations within the Roanoke delta: Station 6 (Middle River), Station 7 (Roanoke just above the Weyerhaeuser diffuser pipe), Station 8 (Cashie River), and Station 10 (Roanoke downstream of Plymouth, Figure 2). Samples were collected at the surface, mid-depth, and bottom with a Van Dorn water sampler. For each station, the discrete samples were composited to form one sample. Periodically, the discrete surface, mid-depth, and bottom samples collected at Station 7 and Station 10 were not composited but were analyzed separately as a check for any vertical variation in water quality. The water sample for each station was stored in four pre-cleaned glass 1-L bottles. Pre-cleaning for three bottles involved acid-washing in 1:1 HCL and flushing with distilled water. The fourth bottle was prepared for metals analysis by soaking in 1:1 HNO_3 for 24 hours and rinsing with distilled water. Water quality analysis was conducted at the Weyerhaeuser Field Station Lab at New Bern, North Carolina, with the exception of metals, soluble organic carbon (SOC), and total organic carbon (TOC). Samples for metals analysis were preserved with 1 ml of HNO_3, iced, and shipped to the Weyerhaeuser Technology Center (WTC) laboratory in Federal Way, Washington, for processing. Water samples were compared to the North Carolina Standards and EPA criteria for selected water quality parameters for protection of fresh water aquatic life (Appendix Table A-1). Laboratory detection limits of various water quality parameters are presented in Appendix Table A-2.

Precipitation Estimates. Lower Roanoke River basin and basin-wide precipitation estimates were available from Roanoke River daily flow graphs produced monthly by the U.S. Army Corps of Engineers (Corps), Wilmington District.

Phytoplankton and Chlorophyll *a*

Phytoplankton and chlorophyll *a* samples were taken at selected stations within the lower Roanoke River, delta, and western Albemarle Sound. Phytoplankton (whole water) samples were taken at the surface by submerging a 250-ml plastic bottle just below the surface of the water and allowing it to fill. Each phytoplankton sample was preserved with Lugol's acetic acid-iodine solution (Wetzel and Likens 1979). An additional 1-L sample was collected and chilled for laboratory measurements of chlorophyll *a*.

Phytoplankton cell densities were determined in the laboratory using the membrane filtration method (APHA 1975). The preserved algae were concentrated by filtering the sample through a 0.45-µm pore size membrane filter. Concentrated algae were counted using an inverted microscope and reported as number of individuals per liter. These counts were converted to volume (cubic microns) by estimating the volume of an average individual of each species with geometric formulae. The total volume of algae per liter was converted to weight by assuming a specific gravity of unity.

Chlorophyll *a* analyses were performed by the standard acetone extraction method (Strickland and Parsons 1972) and reported as micrograms per liter (µg/L).

Zooplankton

Zooplankton samples were taken with nets constructed of 250-µm nitex mesh material, a mouth opening of 0.5 m, and a 1:6 mouth-to-length ratio. A flowmeter with slow speed propeller (General Oceanics model 2030) was mounted in the net frame to estimate the volume of water filtered. The meter was calibrated each season by towing the net over a measured distance with and against currents and winds (Appendix Table A-3). Samples of two-minute duration were taken against the current at river stations, and when possible against the wind or current in the Sound, whichever was strongest. Zooplankton were preserved in 10% buffered formalin containing Rose Bengal dye.

Each zooplankton sample was examined for ichthyoplankton, which was removed prior to processing using a standard subsample method. Each sample was diluted to 500 ml. A 5-ml subsample was removed from the sample, and all organisms were identified (Gosner 1971, Pennak 1978, McCafferty 1981, Merritt and Cummins 1984) to the lowest practical taxon and enumerated. This procedure was repeated two more times. The average number of each taxonomic group was reported as number of individuals per m^3. The zooplankton taxa and their relationships are presented in Table 3.

Length-weight and length-biomass relationships were determined for the most abundant zooplankton groups for later use in zooplankton standing crop estimates and prey availability to ichthyoplankton. For each taxonomic group, individuals were measured using methods of Dumont et al. (1975) and Culver et al. (1985). Conservative estimates of average biomass (g) was calculated based on geometric formulae of the body and assuming that 1 cc of body volume equaled 1 g of weight. This method did not account for antennae or appendages on larger zooplankton species.

Ichthyoplankton

Ichthyoplankton samples for Stations 1-4 were collected by towing a Tucker trawl in an oblique manner against the current for six minutes. The Tucker trawl was constructed of 505-µm nitex mesh material with a 0.5-m^2 mouth opening and 1:6 mouth-to-length ratio. A flowmeter

Table 3. Taxonomic relationships of zooplankton collected from the lower Roanoke River, delta, and western Albemarle Sound, North Carolina, 1984-1991.

- Phylum Cnidaria
  - Class Hydrozoa
    - Order Hydroida
      - Family Hydridae
        - *Hydra* species and *Cordylophora lacustris*
- Phylum Platyhelminthes
  - Class Turbellaria (flatworms)
- Phylum Rotatoria (rotifers
- Phylum Nematoda (nematodes)
- Phylum Tardigrada
- Phylum Annelida
  - Class Polychaeta (polychaete worms)
  - Class Oligochaeta
    - Order Plesiopora pleiothecata
      - Family Naididae
        - *Stylaria lacustris*
        - *Dero* species
      - Family Aeolosomatidae
        - *Aeolosoma leidyi*
  - Class Hirudinea (leeches)
- Phylum Arthropoda
  - Class Arachnoidea
    - Suborder Trombidiformes
      - Hydracarina families
  - Class Crustacea
    - Subclass Malacostraca
      - Superorder Peracarida
        - Order Amphipoda
          - Suborder Gammaroidea
            - Family Gammaridae
              - *Gammarus* species
        - Order Isopoda (isopods)
        - Order Mysidacea (oppossum shrimps)
        - Order Cumacea
        - Order Tanaidacea
      - Superorder Eucarida
        - Order Decapoda
          - Family Paguridae (hermit crabs)
          - Family Palaemonidae (grass shrimps)
    - Subclass Branchiopoda
      - Superorder Oligobranchiopoda
        - Order Cladocera
          - Family Leptodoridae
            - *Leptodora kindti*
          - Family Bosminidae
            - *Bosmina* species
          - Family Daphnidae
            - *Daphnia* species
          - Family Sididae
          - Family Chydorinae

Table 3. Zooplankton taxonomic relationships (continued).

- Subclass Ostracoda (seed shrimps)
- Subclass Copepoda
  - Order Eucopepoda
    - Suborder Calanoida (adult calanoid copepods)
    - Suborder Cyclopoida (adult cyclopoid copepods)
    - Suborder Harpacticoida (adult harpacticoid copepods)
    - nauplius copepods (early stages)
    - other copepodids
  - Order Branchiura
    - Suborder Arguloida
      - Family Argulidae
        - *Argulus* species

Class Insecta
- Subclass Apterygota
  - Order Collembola (springtails)
- Subclass Pterygota
  - Order Ephemeroptera (mayflies)
  - Order Odonata (dragonflies)
  - Order Orthoptera
  - Order Megaloptera (alderflies)
  - Order Hemiptera (true bugs)
    - Family Belostomatidae (giant waterbugs)
    - Family Corixidae
    - Family Gerridae
  - Order Plecoptera (stoneflies)
  - Order Hymenoptera (wasps)
- Subclass Endoptergota
  - Order Trichoptera (caddisflies)
  - Order Neuroptera
    - Family Sisyridae (spongillaflies)
  - Order Coleoptera
    - Suborder Adephaga
      - Family Dytiscidae (predaceous diving beetles)
      - Family Gyrinidae (whirligig beetles)
      - Family Haliplidae
        - *Peltodytes* species (crawling water beetles)
    - Suborder Polyphaga
      - Family Elmidae (riffle beetles)
  - Order Diptera
    - Suborder Nematocera
      - Family Culicidae
        - Subfamily Culicinae (mosquitos)
        - Subfamily Chaoborinae
          - *Chaoborous* species (phantom midges)
      - Family Chironominidae (chironomids)
      - Family Heleidae
      - Family Dixidae
    - Suborder Cyclorrhapha
      - Family Ephydridae (shoreflies)
  - Order Thysanoptera (thrips)

Table 3. Zooplankton taxonomic relationships (continued).

Phylum Mollusca
- Class Bivalvia
- Class Gastropoda

Phylum Chordata
- Subphylum Vertebrata
  - Class Amphibia
    - Order Anura
      - Family Ranidae (tadpoles)

with high speed propeller was mounted in the mouth of the net. Stations 1-4 were sampled by towing with a single net, emptying the cup, and then towing a second time. Each year, Station 5 was sampled with a Tucker trawl by WRC personnel along with Stations 1-4, and with paired nets thereafter in the manner described below.

Ichthyoplankton samples for Stations 6-18, Stations 20-29, Stations 31 and 32, and Station 5 (after WRC personnel terminated sampling efforts each season) were collected by towing paired 0.5-m diameter conical nets in an oblique manner for six minutes. Each conical net was constructed of 505-μm nitex mesh material with a 1:6 mouth-to-length ratio, mounted in a bongo frame. A flowmeter with high speed propeller was mounted in the mouth of each net. Ichthyoplankton for all samples was preserved in 10% buffered formalin containing Rose Bengal dye. Flowmeters were calibrated at the end of each season with the method described previously (Appendix Table A-3).

In the laboratory, larvae and small fish were removed from each ichthyoplankton sample for enumeration and identification. *Morone* larvae were identified and measured (nearest 0.5 mm TL), and stage of development was noted using methods described by Mansueti (1964), Lippson and Moran (1974), and Olney et al. (1983). Stage 1 larvae possessed yolk. Stage 2 larvae had no yolk, and the oil globule may or may not be present and the fish was most likely capable of feeding. Stage 4 fish were juveniles, identified by the presence of adult body shape, full complement of fin rays, and scales.

Morone larvae in feeding condition (determined by the presence of developed jaws and an inflated gas bladder) were examined for gut contents. Each prey item was identified to the lowest taxon practical and enumerated. The average number of each prey item ingested per fish was calculated by counting the total number of each item and then dividing by the number of fish examined that contained prey.

Replicate ichthyoplankton samples taken at each station were converted to number of striped bass larvae per unit volume (number/100 m^3). Density values of the two replicate tows for each station were averaged to reduce the variance component of ichthyoplankton distribution associated with collecting replicate samples.

Study Area Volume Estimates

For standing crop or biomass estimates of phytoplankton and zooplankton, it was necessary to determine the total volume of water contained in the lower Roanoke River, delta distributaries, and western Albemarle Sound. Volumes were estimated from field measurements conducted in the summer of 1989. Using the N.C. Highway 45 bridge as a reference point, cross-sectional profiles of the delta distributaries were taken every 500 m for a total of 106 depth profiles (Appendix B-1). Volume estimates of Batchelor Bay and western Albemarle Sound were made using bathymetric data from commercially available navigation charts (Appendices B-2 and B-3). The estimated volume of the total delta segment of the Roanoke River

(Thoroughfare to river mouth) was 13.4 million m^3; Middle River was estimated at 5.8 million m^3, and Eastmost River was 0.89 million m^3 (Table 4). The Cashie River from the Thoroughfare to its mouth was about 7 million m^3, and the western Albemarle Sound study area was estimated at 973 million m^3 in volume (Table 4). Calculations for volume estimates are presented in Appendices B-4 and B-5.

River Flow

Instream flow of the lower Roanoke River is monitored every 15 minutes by the USGS gage No. 02080500 at Roanoke Rapids, North Carolina (RM 133.6). The gage is located in Halifax County on the right bank 2.8 miles downstream of the Roanoke Rapids Dam. The period of record for this gage is from the fall of 1911 to the current year. Unit values (quarter-hour) are used to determine an average daily discharge measured in cubic feet per second (cfs). Since two to three days are required for a water parcel to travel from the dam to the river mouth (depending on rate of discharge), we used the daily estimates of discharge in the analyses.

Data Analyses

Statistical analyses were performed using the Statistical Analysis System (SAS Institute 1985) on the East Carolina University mainframe computer. Cluster analysis and principal components analysis were used on each data set to assist in describing similar environments and/or similar communities within the delta, Batchelor Bay, and western Albemarle Sound. Data sets included water quality, phytoplankton, chlorophyll *a*, zooplankton, and larval fish (striped bass, white perch, and *Morone* species. Stepwise procedures were used to identify variables that were significantly related to density and biomass estimates of phytoplankton, zooplankton, and larval fish. Additional testing of specific aspects of the data sets are described as part of the results section.

Table 4. Volume estimates (m^3) of the lower Roanoke River, delta, and western Albemarle Sound used in biomass or standing crop calculations for phytoplankton, zooplankton, and larval fish. Refer to Appendix B for maps and calculation methods.

Watershed section	Volume (m^3)
Roanoke River (delta segment only):	
Thoroughfare to Middle River	3,765,763
Middle River to Highway 45 bridge	6,886,479
Highway 45 bridge to mouth	2,764,608
Total delta segment:	13,416,850
Middle River	5,812,076
Eastmost River	888,542
Thoroughfare-Cashie River:	
Thoroughfare to Highway 45 bridge	4,986,967
Highway 45 bridge to mouth	1,980,132
Total Thoroughfare-Cashie segment:	6,967,099
Western Albemarle Sound study area: Batchelor Bay east to old Norfolk and Southern Railway bridge	973,386,800

RESULTS

Water Quality

River Flow. The mean instream flow of the lower Roanoke River for 1984 (January-December) was higher (10,091 cfs) than the long-term mean annual flow (8,120±8,622 cfs), ranking 16th in the 79-year period of record (1912-1990). River flow for the second quarter (April-June) was 13,836 cfs, which was the 7th highest second quarter period on record (Table 5). High stable flows (20,000 cfs) from 1 April through 15 May characterizied 38.5% of the days (35 of 91) in the second quarter, caused mainly by higher than normal precipitation in April (4.59 inches) and May (6.83 inches) (Table 6). April high flows were followed by variable flows between about 5,000 and 15,000 cfs until mid-June, when minimum flows (2,000 cfs) were recorded (Figure 3). June rainfall (2.49 inches) was about 1.5 inches lower than normal in 1984 (Table 6).

Mean annual instream flow for calendar year 1985 (7,392 cfs), ranking 49th in the 79 years of record, was lower than the average annual discharge; flows for the April-June period were the lowest on record (3,583 cfs) (Table 5). Instream flow of less than 3,000 cfs was reported for 63.7% of the days (58 of 91), and only 20.9% (21 of 91) of the days had flows of 6,000 cfs or more. The 6,000 cfs plateau evident in Figure 3 was a result of flow augmentation by the Corps for striped bass spawning activity. Rainfall activity below Kerr Dam was considerably lower than normal (Table 6).

Drought conditions prevailed in 1986; the mean annual discharge of 4,157 cfs was the second lowest for the period of record (Table 5). Mean instream flow for the April-June period was 4,252 cfs, which was slightly greater than that observed in 1985 but still placed the period 76th in the 79-year record. River flow was less than 3,000 cfs for 42 days (46.2%), and only 20 days (22.0%) had flows of 6,000 cfs or more, again primarily during the flow augmentation period for striped bass spawning activity in late April through mid-May (Figure 3). Precipitation below Kerr Dam was 1.73 in below normal in April, 2.21 in below normal in May, and 3.56 in below normal in June (the lowest recorded June rainfall for the period of record) (Table 6).

Flood conditions prevailed during the spring of 1987, causing the mean annual discharge of 12,213 cfs to be the third highest for the period of record. The April-June instream flow (19,596 cfs) was the highest ever observed, ranging as high as 35,000 cfs in late April through mid-May (Figure 3); nearly half of the days (44 of 91) had flows of 20,000 cfs or more. Below-dam rainfall was about 2.4 in above normal for April (Table 6).

In 1988, the mean annual instream flow of the lower Roanoke (4,668 cfs) was the third lowest on record (76 of 79 years), but the April-June average of 5,412 cfs was close to the historical mean from mid-April through May (Figure 3). The stable flows were the result of moderate inflow to the upper watershed, near normal rainfall in the lower watershed (Table 6),

Table 5. Mean annual and second quarter (April-June) instream flows (cfs), ± standard error (S.E.), of the lower Roanoke River, North Carolina, and number of days within specific flow regimes, 1984-1990 based on daily records of the USGS gage at Roanoke Rapids. Mean annual flows, n=365 days (1985-87, 1989, 1990); n=366 days (1984, 1988). Ranking is for the period of record (Mean annual discharge, 1912-1990, n=79 years; Apr-Jun discharge, 1912-1991, n=80 years).

	Annual discharge[1]			Apr-Jun discharge[2]			April-June period (n=91 days): Flow <3,000 cfs		3,000≥X <6,000 cfs		6,000≥X <10,000 cfs		10,000≥X <20,000 cfs		Flow ≥20,000 cfs	
Year	Mean	S.E.	Rank	Mean	S.E.	Rank	Days	%	Days	%	Days	%	Days	%	Days	%
1984	10,091	359	16	13,836	716	7	12	13.2	2	2.2	16	17.6	26	28.6	35	38.5
1985	7,392	321	49	3,573	197	80	58	63.7	12	13.2	21	23.1	0	0	0	0
1986	4,157	146	78	4,252	206	76	42	46.2	29	31.9	18	19.8	2	2.2	0	0
1987	12,213	494	3	19,596	1,207	1	6	6.6	6	6.6	15	16.5	20	22.0	44	48.4
1988	4,668	176	76	5,412	282	71	27	29.7	22	24.2	38	41.8	4	4.4	0	0
1989	10,747	332	9	13,699	596	8	1	1.1	9	9.9	22	24.2	29	31.9	30	33.0
1990	10,495	353	12	13,386	574	10	3	3.3	2	2.2	32	35.2	42	46.2	12	13.2
1991	incomplete data			10,992	554	19	5	5.5	5	5.5	53	58.2	13	14.3	15	16.5

[1]Mean flow (±S.D), 1912-1990 = 8,120 ± 8,622 (n=28,855 days); min=472 cfs; max=254,000 cfs.
[2]Mean Apr-Jun flow (±S.D.), 1912-1991 = 8,994±7,435 (n=7,280 days); min=1,080 cfs; max=78,000 cfs.

Table 6. Normal and observed rainfall (inches) for the Roanoke River basin downstream of Kerr Reservoir (RM 178.7), and basinwide, for April-June 1982-1992 (U.S. Army Corps of Engineers data).

	Below Kerr Dam						Basinwide					
	Normal			Observed			Normal			Observed		
Year	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun
1963	3.37	4.02	3.91	1.55	2.83	2.59						
1964	3.26	4.02	3.91	2.20	1.30	2.45						
1965	3.26	3.77	3.78	2.04	1.98	8.30						
1966	3.16	3.62	4.16	1.49	6.38	3.55						
1967	3.03	3.84	4.11	1.88	3.24	2.39						
1968	2.95	3.79	3.99	3.21	5.20	3.05						
1969	2.95	3.79	3.99	3.05	3.24	4.12						
1970	2.95	3.79	3.99	4.09	2.36	3.12						
1971	2.95	3.79	3.99	2.57	6.36	3.41						
1972	2.95	3.79	3.99	2.32	5.03	4.52						
1973	2.95	3.79	3.99	4.62	4.53	5.95						
1974	2.95	3.79	3.99	2.56	5.68	2.65						
1975	2.95	3.79	3.99	2.23	3.23	2.27						
1976	2.95	3.79	3.99	0.85	3.73	4.39						
1977	2.95	3.79	3.99	2.66	5.44	3.69						
1978	2.90	4.08	3.87	4.94	4.85	5.60						
1979	2.98	4.11	3.94	4.30	6.09	5.87						
1980	2.98	4.11	3.94	3.15	2.85	2.84						
1981	2.98	4.11	3.94	1.41	4.96	3.10						
1982	2.98	4.11	3.94	3.04	2.56	4.83						
1983	2.98	4.11	3.97	5.99[A]	3.99	2.48						
1984	2.98	4.11	3.97	4.59	6.83	2.49						
1985	3.13	4.19	3.88	1.13	3.03	3.32						
1986	3.13	4.19	3.88	1.40	1.98	0.32[B]						
1987	3.13	4.19	3.88	5.53	2.21	3.44						
1988	3.01	4.09	3.75	4.67	3.87	3.68						
1989	3.01	4.09	3.75	6.41	5.16	8.41	3.36	3.89	3.84	4.02	5.76	7.95
1990	3.22	4.06	3.87	3.37	5.83	2.34	3.40	3.87	3.83	3.51	7.55	1.76
1991	3.22	4.06	3.87	2.62	1.46	2.86	3.40	3.87	3.83	2.94	3.08	2.68

[A] Maximum observed April rainfall since 1952.

[B] Record low observed June rainfall.

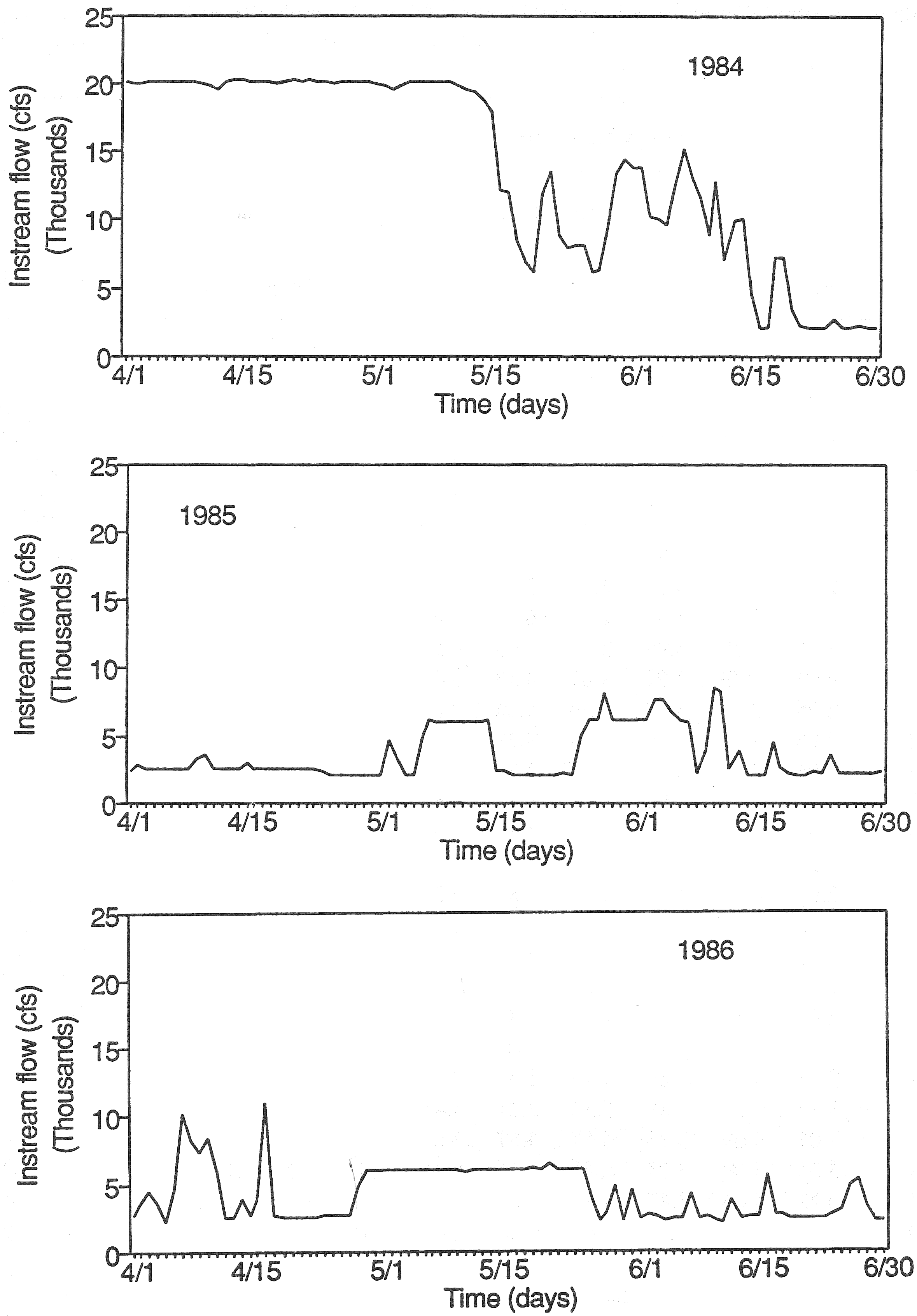
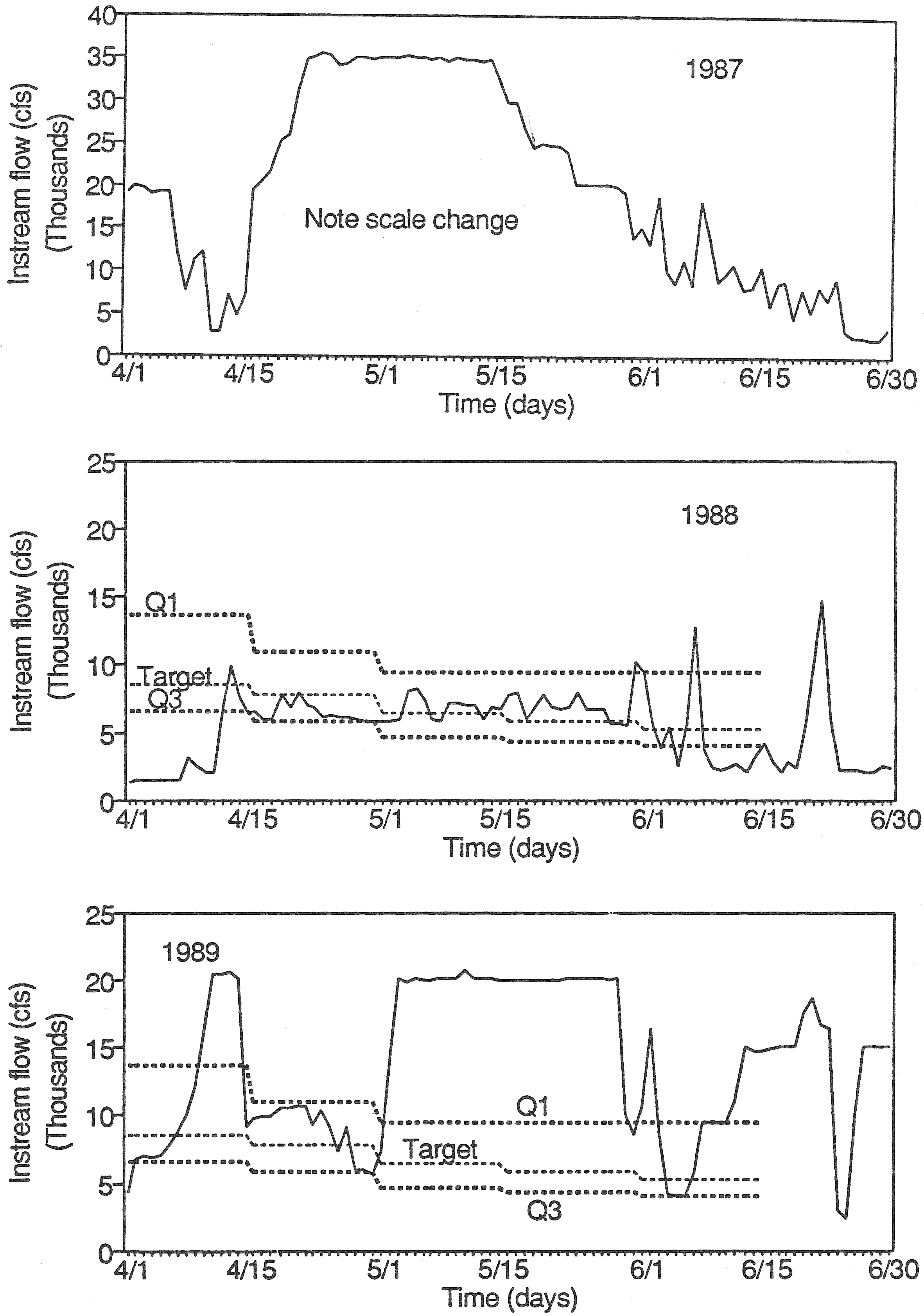


Figure 3. Average daily instream flow of the lower Roanoke River, North Carolina, for the period April through June 1984-1991 as recorded by U.S. Geological Survey gage at River Mile 133.6.



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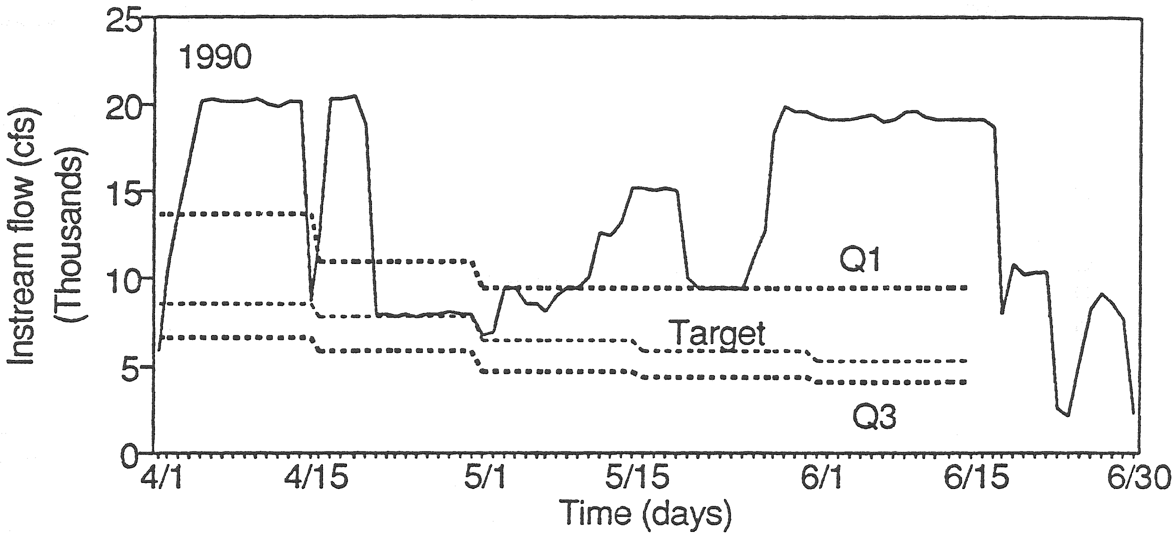


Figure 3. (continued).

and an effort by the Corps and Virginia Power Company to release reservoir waters in a manner consistent with a flow regime under development by the Roanoke River Water Flow Committee (Flow Committee) (Manooch and Rulifson 1989). Only 4.4% of the days had a mean instream flow $\geq$10,000 cfs (Table 5).

Instream flow averaged 10,747 cfs in 1989 caused in part by a wet spring: 3.4 in higher than normal in April, followed by 1 in above normal in May and about 4.5 in above normal in June (Table 6). An initial attempt by the Corps to stay within the historical 25%-75% quartiles of river flow were thwarted by the need to evacuate Kerr Reservoir in early April (Figure 3). A second attempt to remain within the Flow Committee guidelines ended quickly and resulted in three weeks of discharge at about 20,000 cfs throughout May. A third attempt to meet the guidelines in June was not possible due to excessive freshwater inflow. About 65% of the days during the April-June period were flows $\geq$10,000 cfs (Table 5).

The 1990 mean annual instream flow (10,495 cfs) ranked 12th for the period of record and the April-June mean flow of 13,386 cfs was similar to that observed in 1989 (Table 5). High flows of 20,000 cfs in the first half of April were regulated to be within the Flow Committee guidelines in the later half of April, but high inflow in mid-May forced a deviation from the target instream flows (Figure 3). An attempt to return to flow guidelines failed after a basinwide May rainfall of 7.5 in, which resulted in a 20,000 cfs discharge from late May through mid-June.

Moderately high and stable flows in March 1991 increased to about 20,000 cfs through 20 April, when flows ranged between 6,000 and 9,000 cfs through May (Figure 3). Slightly over half (58%) of the days in the second quarter were comprised of flows between 6,000 and 10,000 cfs. Rainfall in March (5.14 inches) was 1.27 inches above normal; April, May and June rainfall was below normal (Table 6).

Water Temperature. The pattern of water temperature changed each year as a function of the seasonality of prevailing air temperature, weather fronts, and instream flow regulated primarily by discharge of reservoir waters. In general, water temperatures were warmer in Batchelor Bay and western Albemarle Sound than in the lower Roanoke River and delta at the same time (Figure 4). Warmer waters early in the spawning season were observed in 1985 and 1986, probably due to solar heating of shallow river waters caused by the drought. Cooler waters in April were common to 1987, 1988, 1989, 1990, and 1991 (Figure 4; Appendix Table A-5).

Dissolved Oxygen. In general the dissolved oxygen content of the lower River, Batchelor Bay, and western Albemarle Sound remained above 4 mg/L every spring, with notable exceptions during high flow periods in 1987 and 1989 (Figure 5). Most likely these depressed dissolved oxygen events were caused by the flushing of stagnant floodplain waters into the main river, Bay and Sound. Usually river waters had higher dissolved oxygen content compared to Batchelor Bay; Albemarle Sound waters in mid-June were usually slightly higher in oxygen content than either the River or Bay (Appendix Table A-6). A more appropriate way of assessing whether waters were adequately oxygenated is to present the values as percent

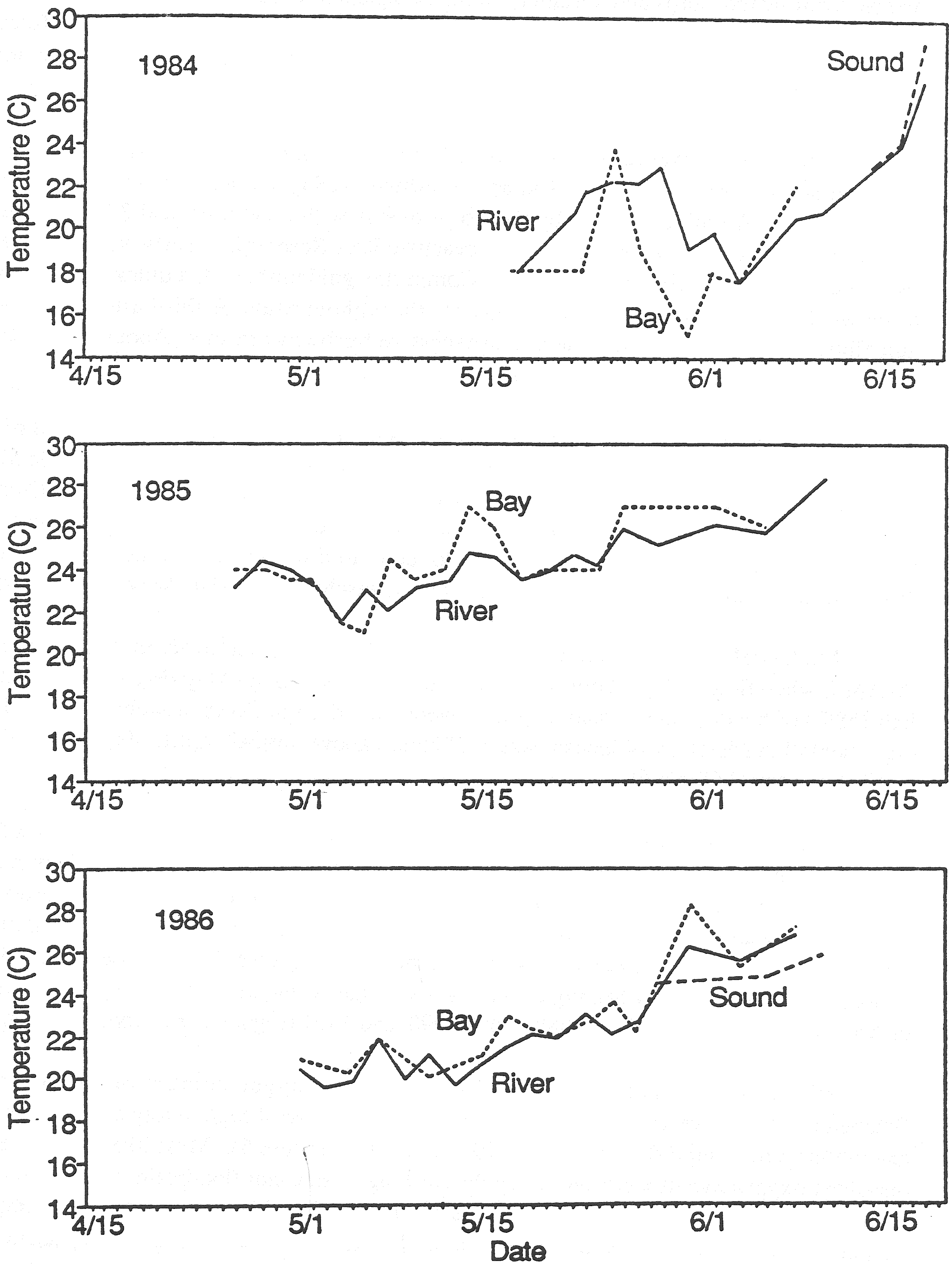
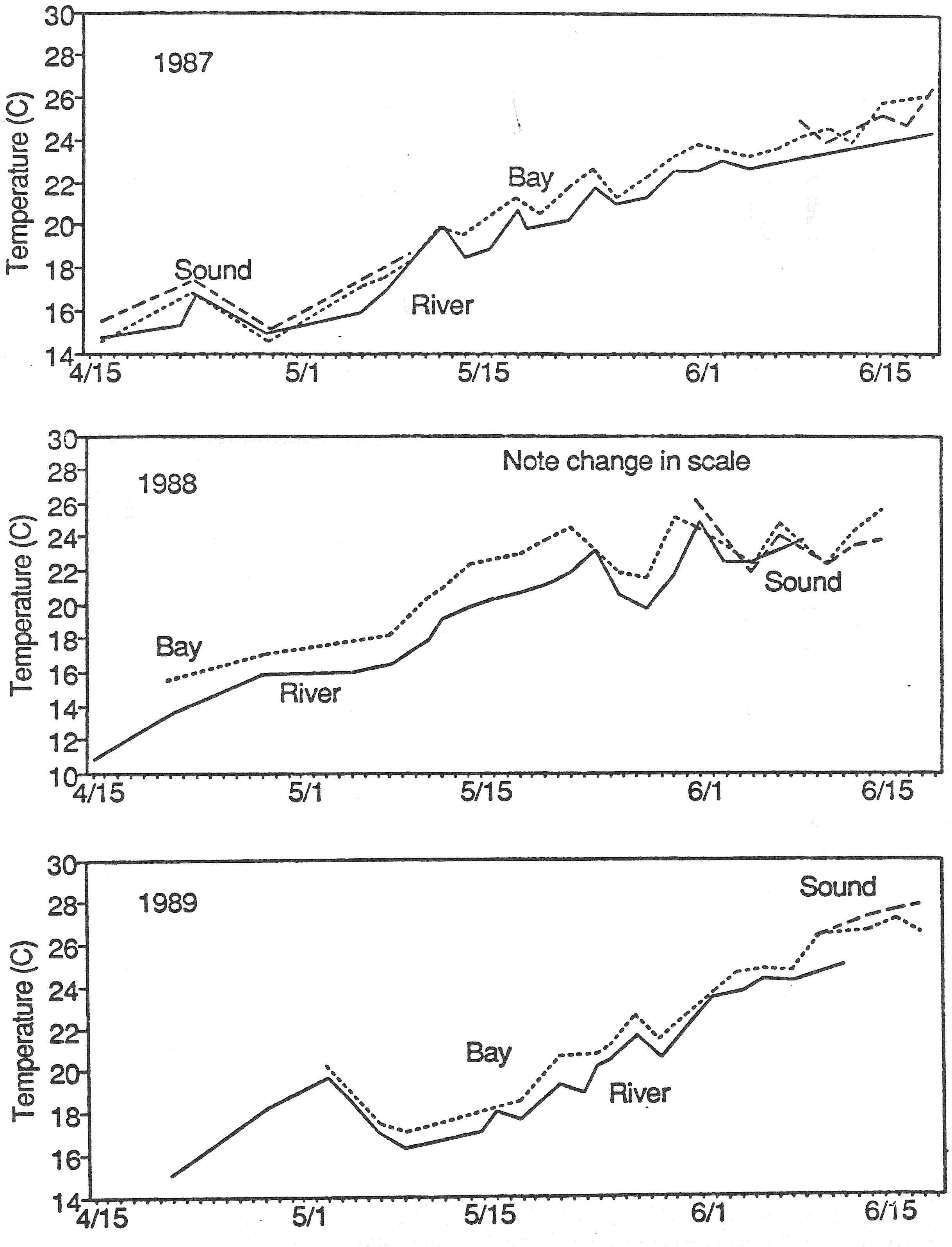


Figure 4. Average water temperature (°C), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.



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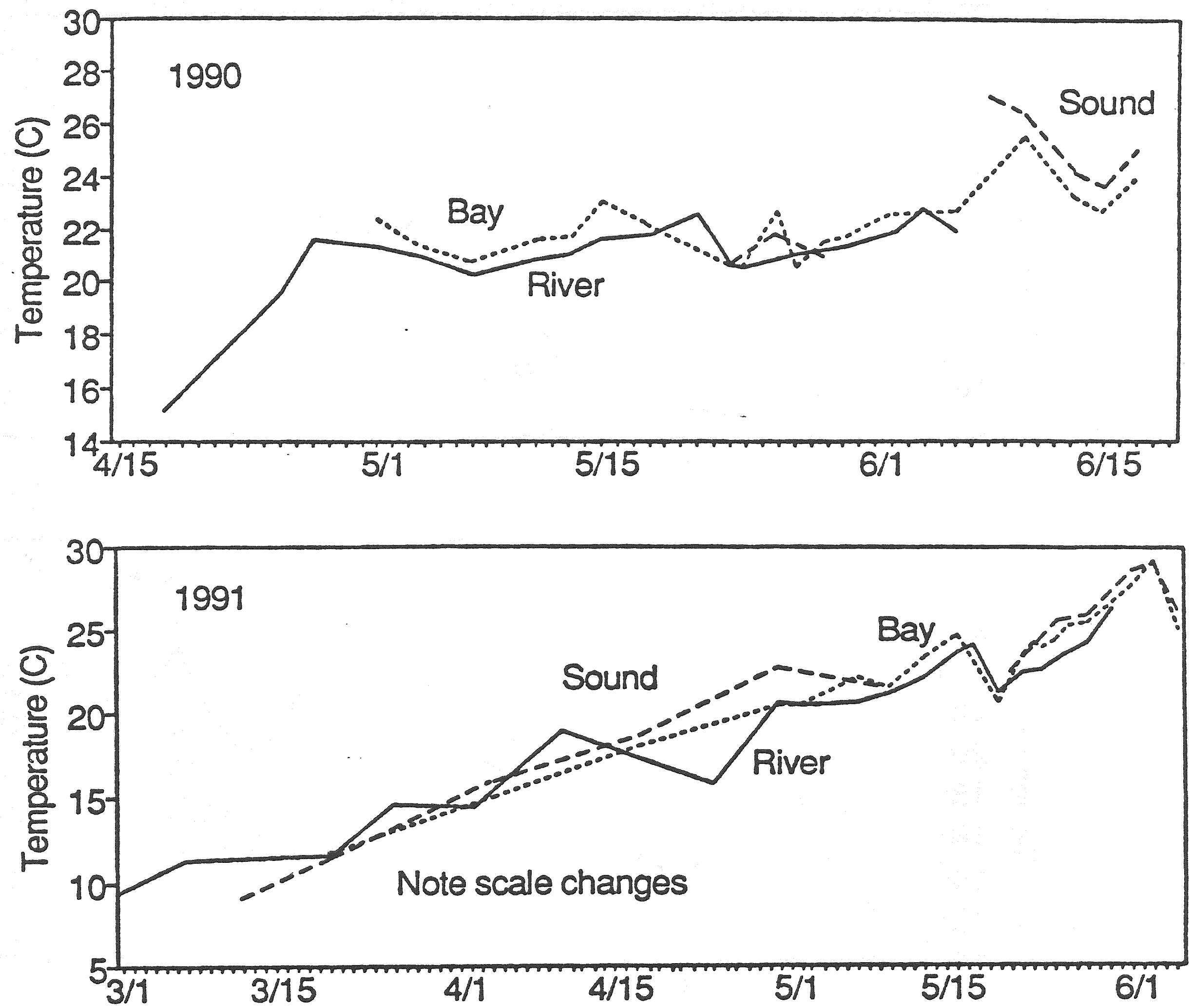

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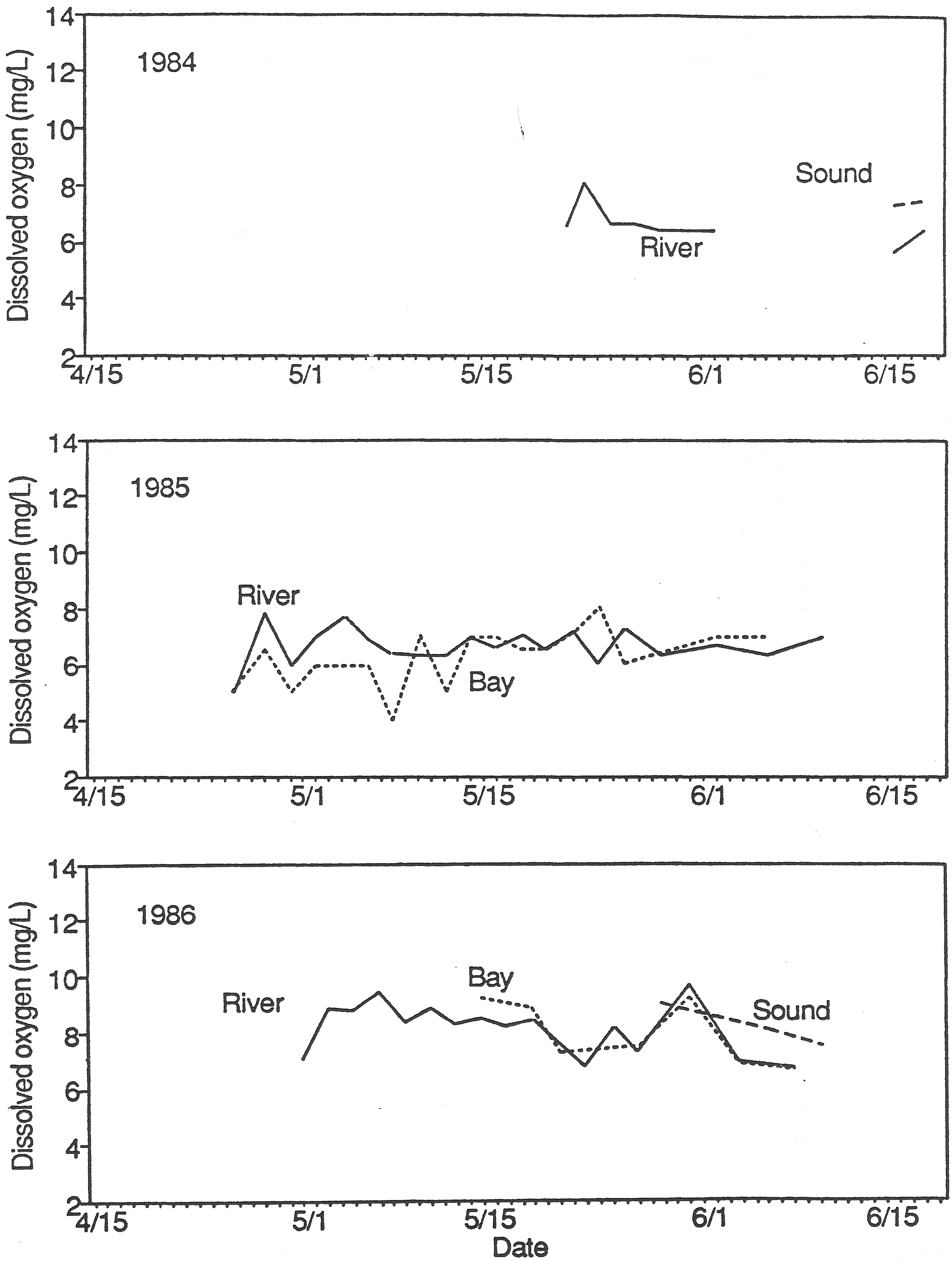
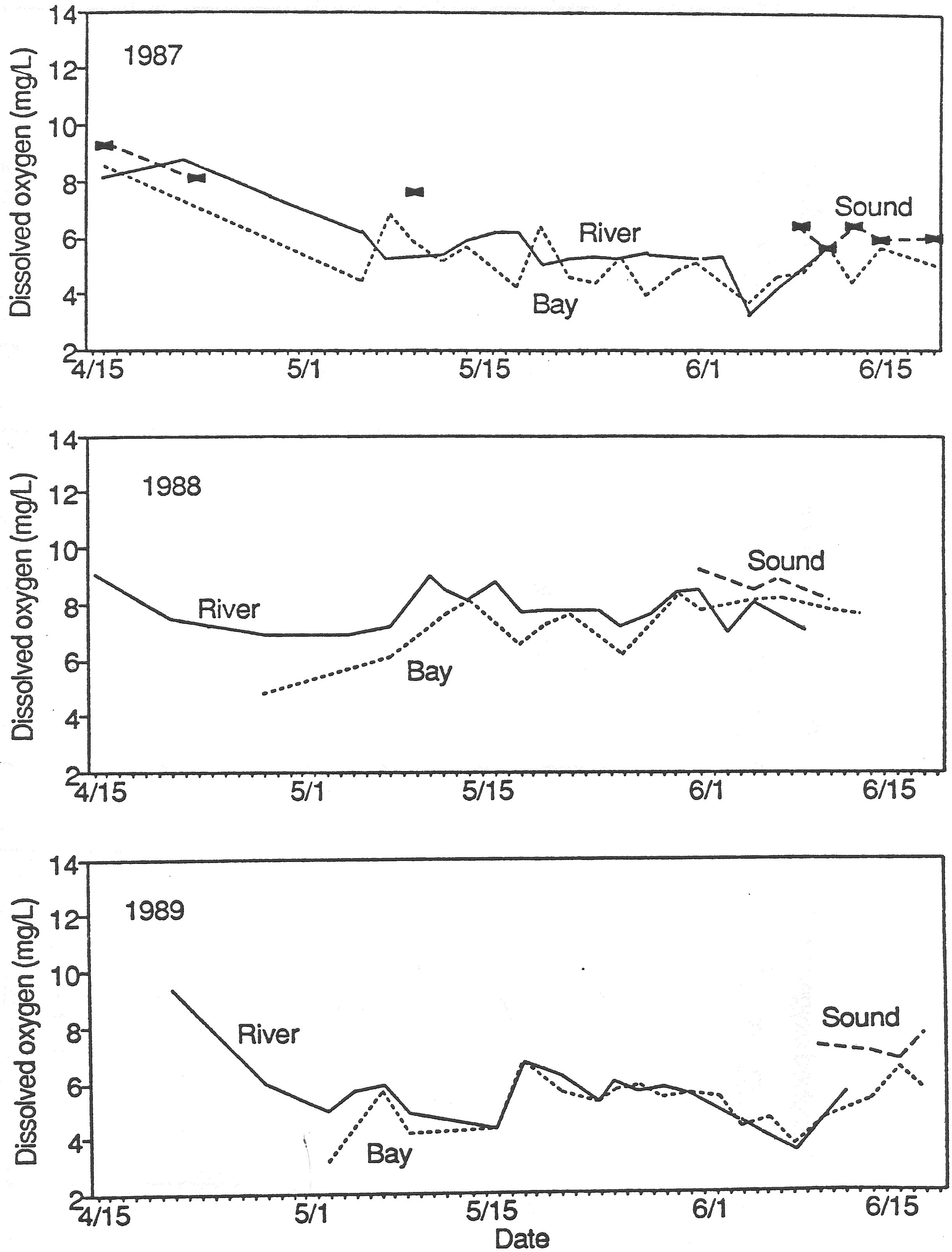


Figure 5. Average dissolved oxygen levels (mg/L), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.



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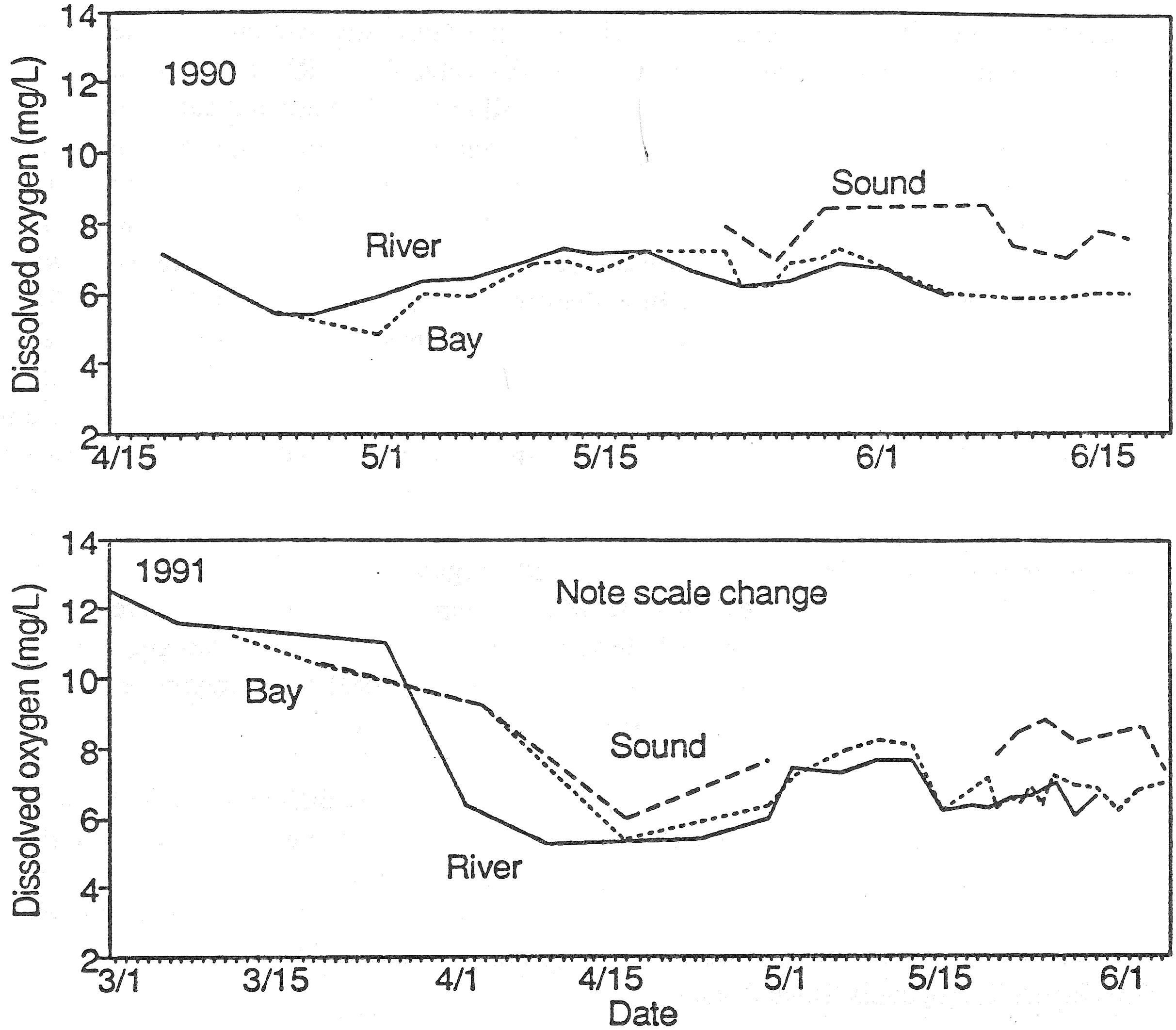


Figure 5. (continued).

saturation, which takes into account the prevailing water temperature and the theoretical concentration of dissolved oxygen. In 1985, oxygen saturation was fairly stable, ranging from 60-80% for most of the spawning season (Appendix Table A-7). River waters were more highly saturated compared to Batchelor Bay in late April and early May, but saturation levels were similar after mid-May (Figure 6). Dissolved oxygen levels were closer to saturation in 1986, ranging from 80-100% and more on occasion (Figure 6). Albemarle Sound waters were close to or exceeding 100% saturation in June. High river flow of April-June 1987 was reflected in stable moderate levels (60-80%) of dissolved oxygen saturation. In general river waters had slightly higher values than Batchelor Bay; dissolved oxygen saturation in Albemarle Sound was higher than either the River or Bay in June, but remained near 80% saturation. Dissolved oxygen values were low in April of 1988 but increased over the season to near 100% by June (Figure 6). Bay waters were slightly less saturated than river waters until June; again, Sound waters were at or above 100% saturation in early summer. In 1989, a dissolved oxygen sag was evident throughout much of the spawning season. Dissolved oxygen saturation dropped to near 40% on several occasions. Similarly low and stable values were observed in April 1990, increasing only slightly in mid-May. Albemarle Sound dissolved oxygen values were much higher in June than either the River or Bay (Figure 6). In 1991, March samples indicated that dissolved oxygen in all three areas were close to or exceeded 100% saturation, but in April an oxygen sag was noted. These low oxygen saturation levels persisted through April 1991 when moderate increases were noted in May and June (Figure 6, Appendix Table A-7).

Surface Water pH. Patterns of surface water pH were different for each year. In 1986 waters were acidic much of the time (Figure 7) dropping briefly to a low of 6.0 in the third week in May. In 1987, surface waters of the Bay and Sound were more acidic than river waters until mid-May, most likely caused by the flushing of darkly-stained and acidic floodplain waters into the main river. For the years 1988-1991, River, Bay and Sound waters remained near or above 7.0 (Figure 7, Appendix Table A-8).

Salinity. The lower Roanoke River and western Albemarle Sound are oligohaline (0.0-0.4 ppt) each year during the April-June period. Measurements indicate short-term fluctations in salinity similar to what might be expected with an internal seiche (Figure 8). Although Bay and Sound waters averaged slightly higher in salinity, occasionally some river stations were more saline due to prevailing water currents. On many occasions the northern Albemarle Sound stations were more saline than southern counterparts (Appendix Table A-9). Whether the western Sound and River are oligohaline or fresh depends on the amount of ocean water entering through the barrier island inlets, especially Oregon Inlet, as a function of prevailing weather patterns (Appendix Tables A-12 and A-13) and freshwater input to Albemarle Sound. In 1991, essentially no salinity was measured in the Sound or River until mid-May even though freshwater input to Albemarle Sound was moderate to low during the same period (Figure 8).

Special Water Quality Studies. Special water quality studies were conducted in 1988 and 1990 with the cooperation of Weyerhaeuser Company and East Carolina University (Rulifson et al. 1990, Herrmann and Rulifson 1991); results of these studies are summarized in

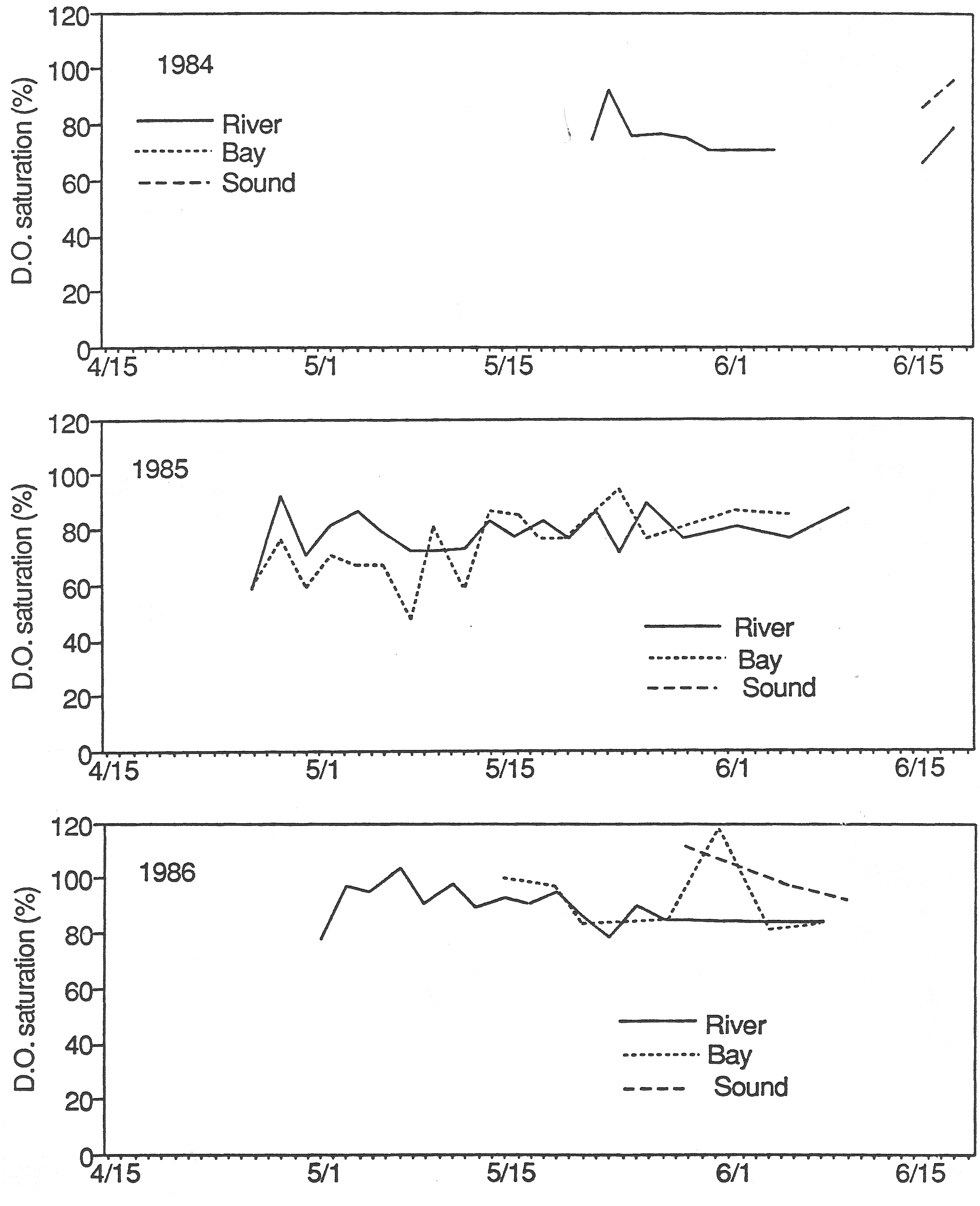
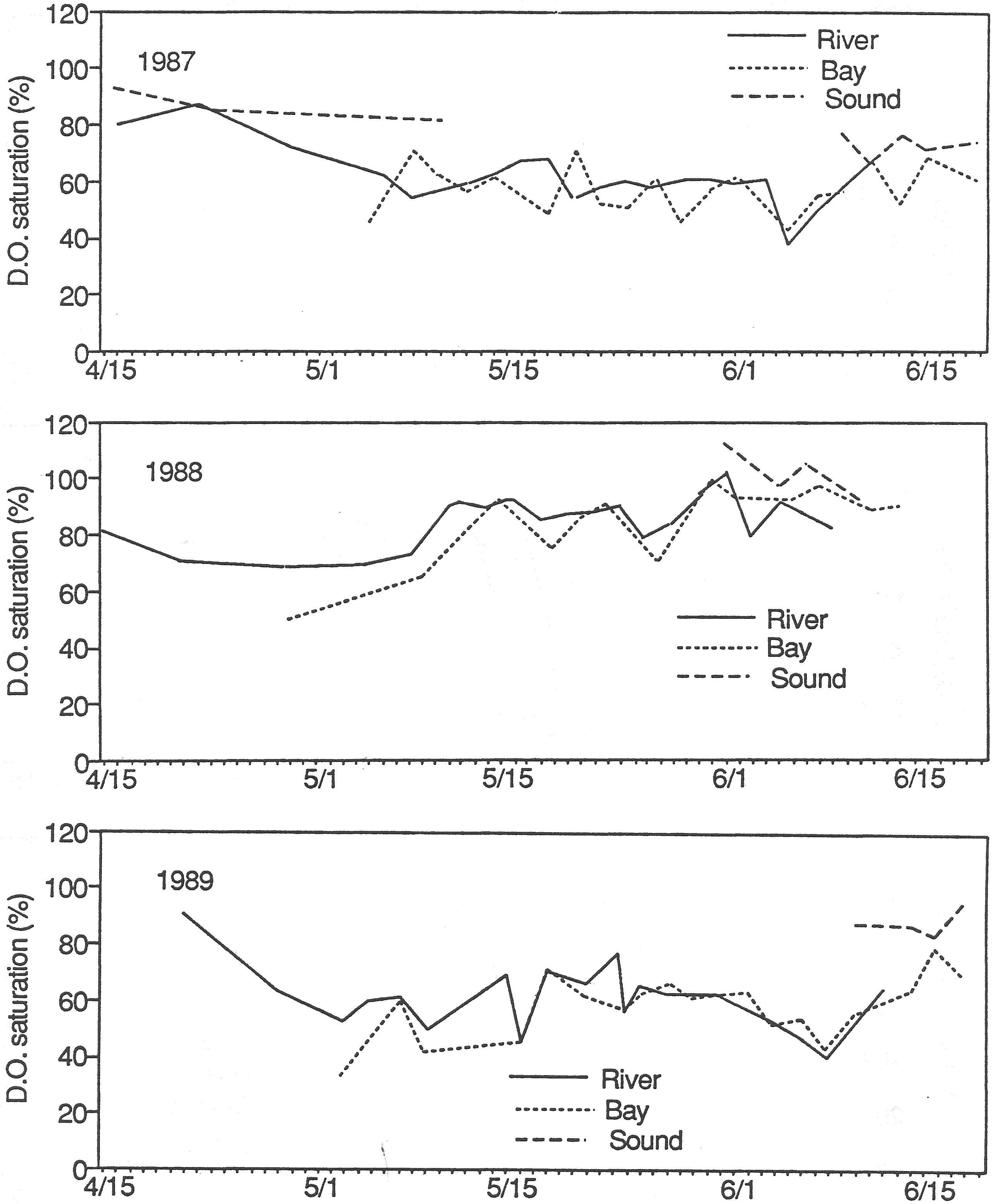


Figure 6. Average dissolved oxygen saturation (%), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.



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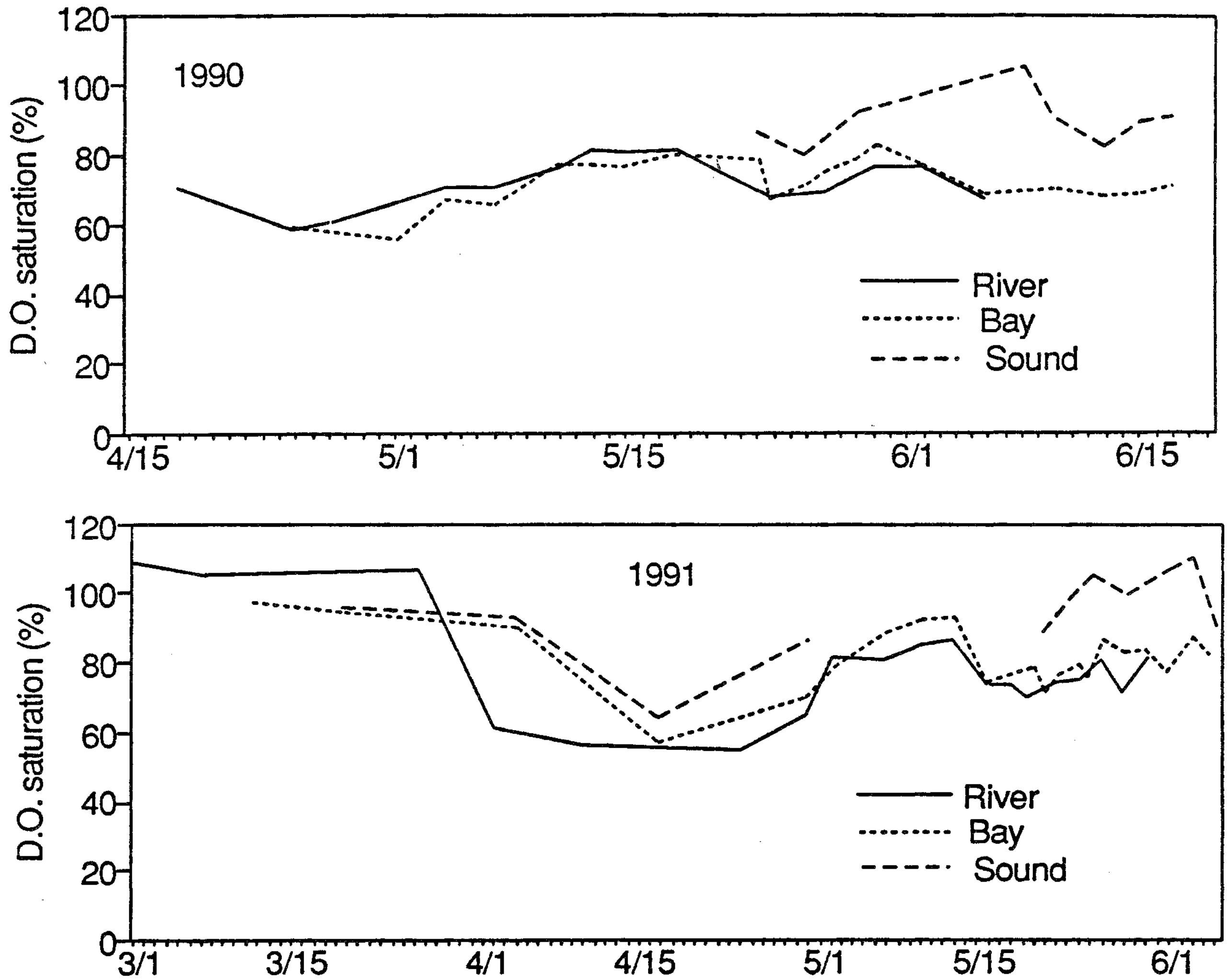

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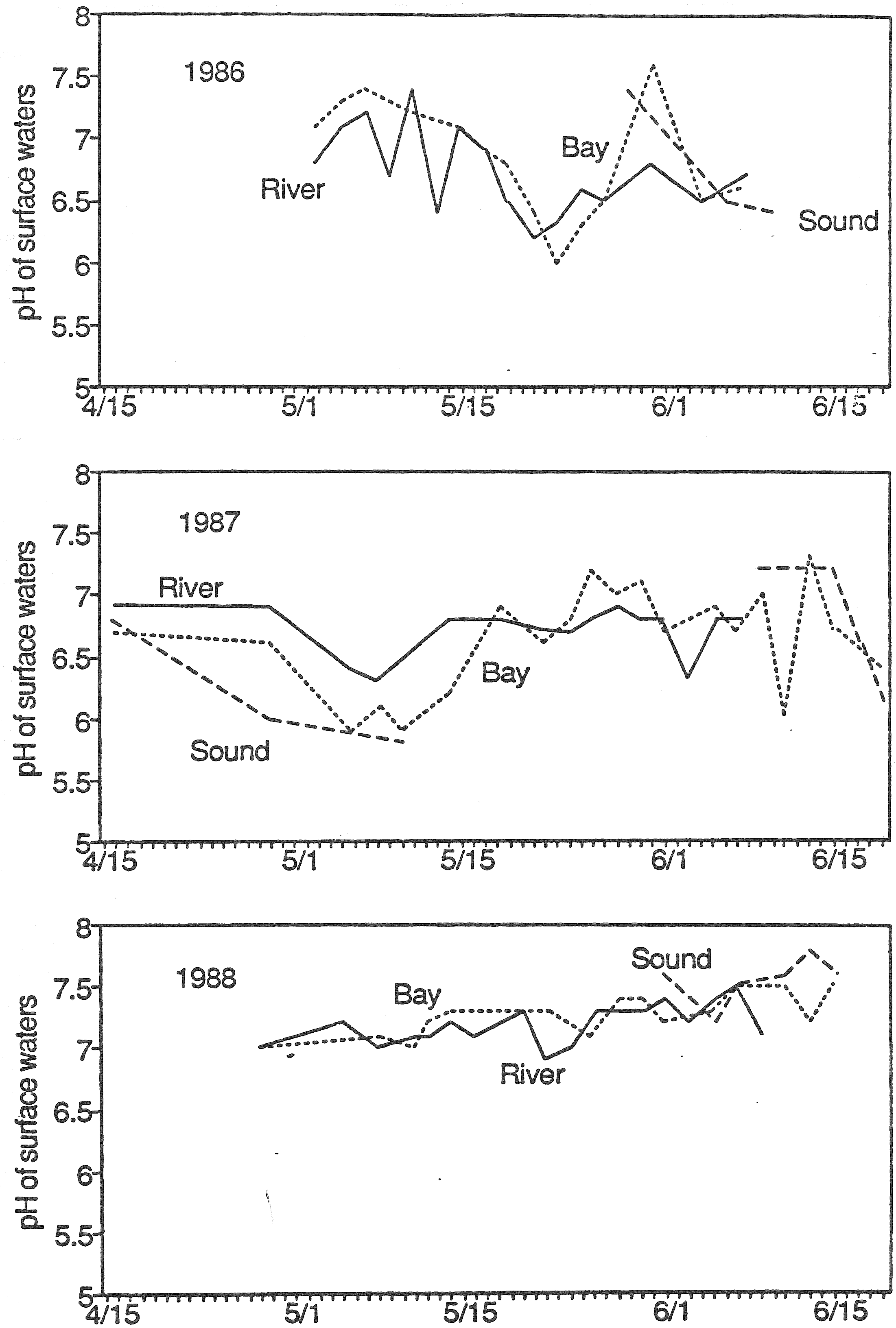
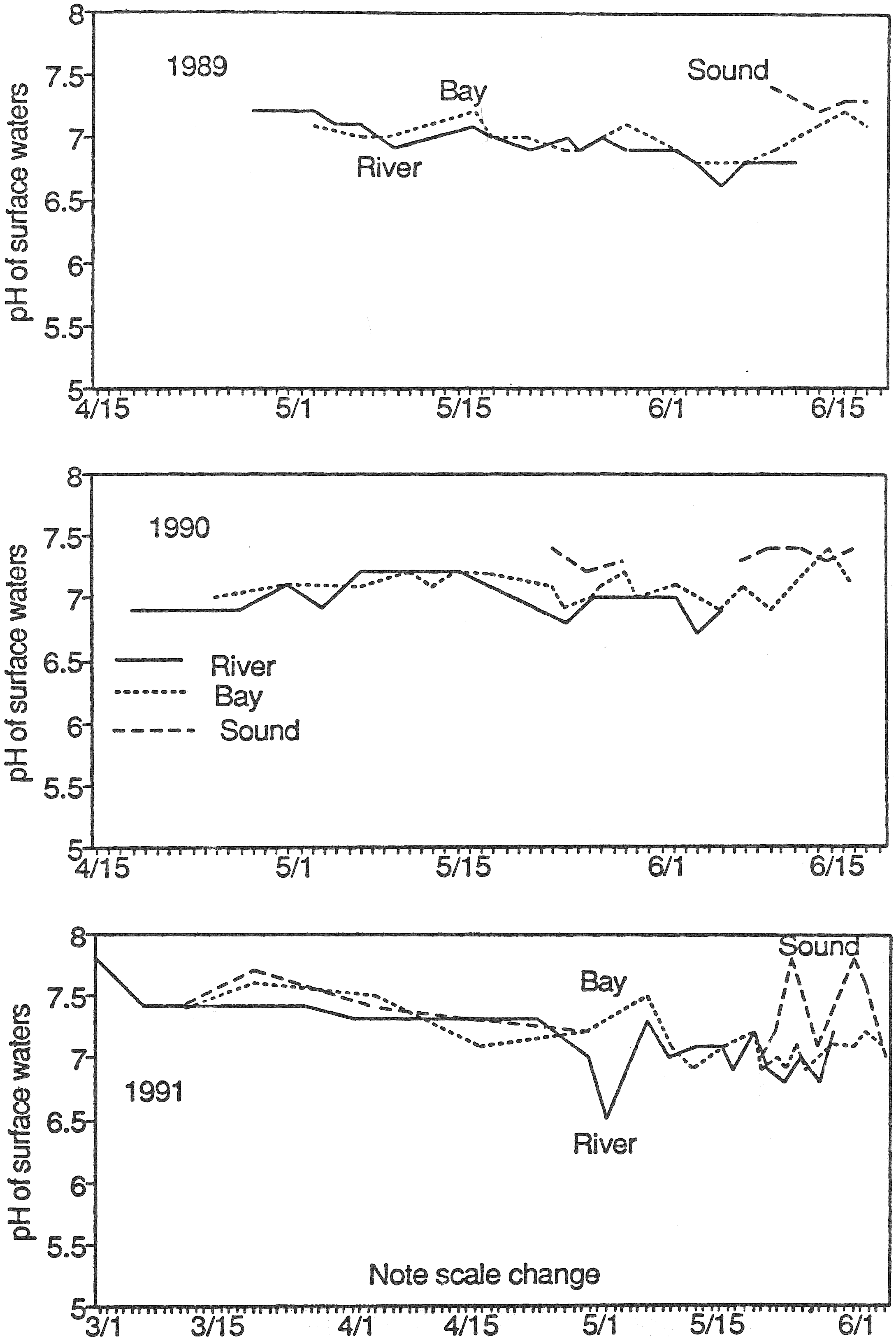


Figure 7. Average surface water pH, by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.



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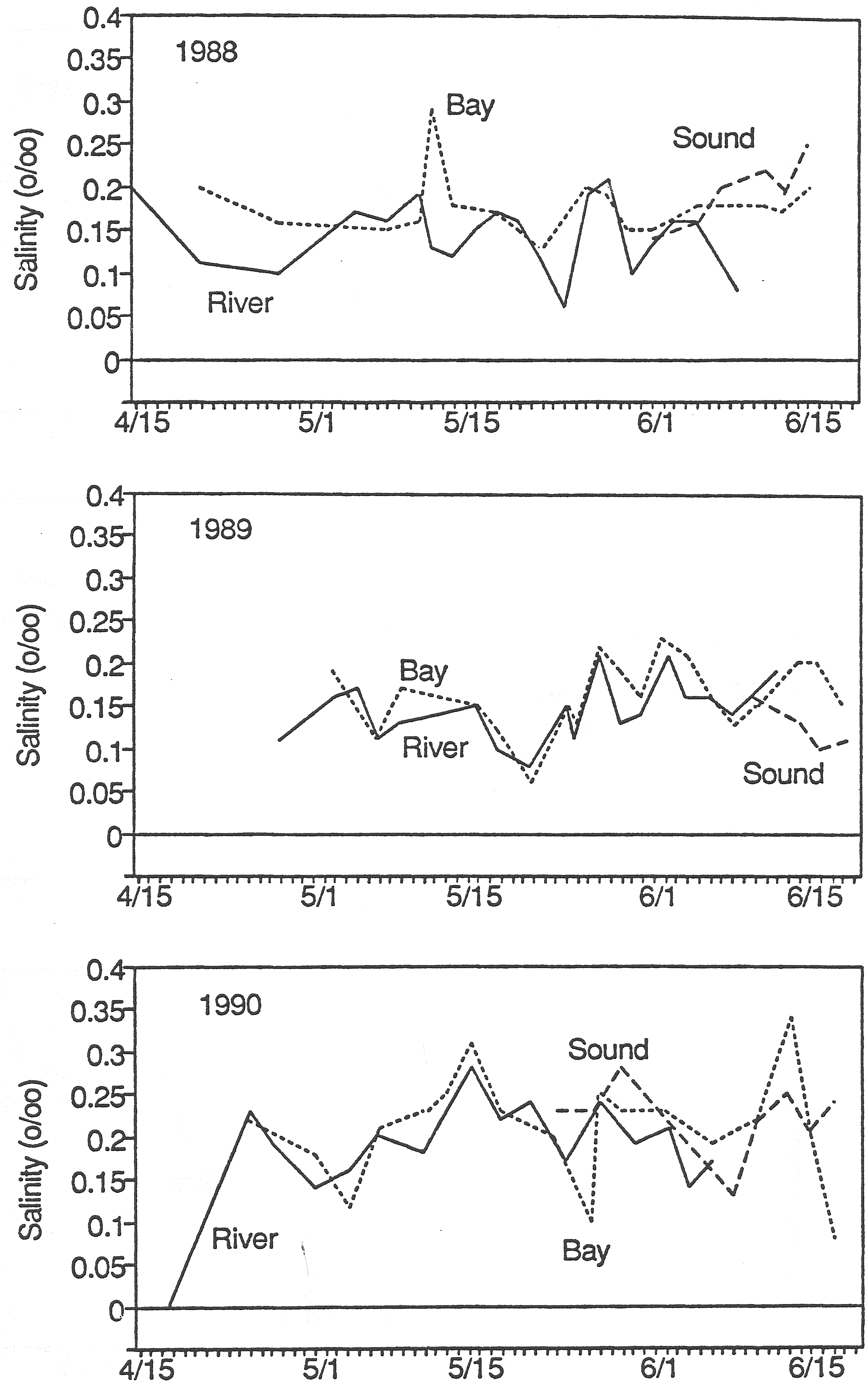


Figure 8. Average salinity (ppt), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1988-1991.

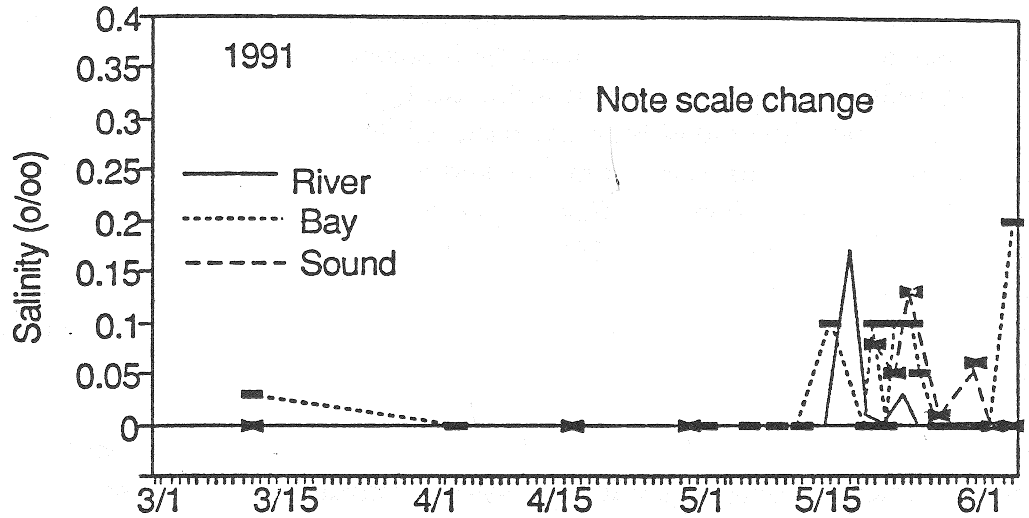


Figure 8. (continued).

this section. Various aspects of water quality upstream (River Mile 105 in 1988, RM 117 in 1990) were compared to that collected within the Roanoke River delta (Stations 5, 6, 7, 8, 10) (Figure 2). In 1988, river flows remained within the Q_1-Q_3 flow regime recommended by the Flow Committee through the end of May and exceeded the range in June (Figure 3). Therefore, we expected higher concentrations of metals and total suspended solids (TSS), except for parameters related to swamp flooding. Flooding of the swamp should increase some parameters such as color and total organic carbon (TOC). In 1990, April river flows were within the Flow Committee's Q_1-Q_3 flow regime but May flows exceeded the target maximum (Figure 3). The higher flows should have resulted in diluted concentrations of most compounds and heavy metals except those related to swampland flooding.

Upstream, the average values for solids, turbidity, and nitrogen and phosphorus species (except for NO_2/NO_3-N) were higher in 1988 when instream flow was lower and more stable (Table 7). Nitrate and sulfate were higher in 1990, perhaps due to input from the atmosphere rather than swamp input, which would have appeared as reduced forms of N and S. Also, carbon was higher in 1990, presumably due to swamp input with higher runoff. Metals concentrations were higher in 1988, with the lower, more stable flows; the average barium (Ba) concentration was the same in both years (Table 7).

In the delta, two stations showed consistent differences from each other, and from the other stations, in both years: Station 10 (Highway 45 bridge downstream of Plymouth), and Station 8 (Cashie River). Several parameters including color, TKN, NH_3-N, SO_4, Ca, and Na were higher at Highway 45 bridge due to the Plymouth mill wastewater discharge. The mill effluent is highly colored and contains calcium and $NaSO_4$ from the wood pulping process. Also, NH_3 is added to the treatment system to promote biological oxidation of the mill effluent. At the Cashie Station, the adjacent swampland bordering most of the shoreline affected several water quality variables. Carbon was higher in the Cashie River, while alkalinity, calcium, and SO_4 were lower (Table 7).

Several water quality parameters in the Delta were related with the prevailing instream flow. Solids (TSS) and metals were higher in the lower flows of 1988, while increased alkalinity, nitrate, and sulfate were observed in the higher flows of 1990 (Table 7). These results were similar to those obtained for the upstream study.

In both years, most water quality parameters were lower upstream and higher in the delta, especially TKN, NH_3, and metals such as Al, Fe, K, and Na (Table 7). Calcium was a notable exception to the trend. Sources of the increased values downstream include sampling traces of pulp mill effluent at Station 10 (increased TKN, NH_3N, Na) and swamp drainage (color, Al, Fe). Low average values for solids at the upstream sites may be due to settling in upstream reservoirs.

Table 7. Upstream and Roanoke River delta water quality comparisons for 1988 and 1990. Upstream 1988 = River Mile 105; 1990 = RM 117. Units in mg/L unless otherwise noted.

	1988		1990	
Water quality parameter	Upstream	Delta	Upstream	Delta
pH	7.2	7.4	7.4	7.2
Alkalinity	27	25	26	27
Color	22	51	22	52
Turbidity	12.3	19.3	9.4	18.0
TSS (total suspended solids)	13.8	19.4	8.8	17.2
VSS (volatile suspended solids)	2.5	3.4	1.8	2.7
BOD5 (biological oxygen demand)	1.3	1.2	1.0	1.3
TOC (total organic carbon)	6	14	8	9
SOC (suspended organic carbon)	4	10	6	8
TKN (total Kjeldahl nitrogen)	0.33	0.51	0.34	0.49
NH_3N	0.06	0.10	0.03	0.08
NO_2/NO_3N	0.15	0.18	0.20	0.21
TPO_4P	0.15	0.17	0.11	0.15
OPO_4P	0.05	0.07	0.06	0.07
SO_4	11.7	10.7	18.5	25.2
Al	0.49	0.77	0.35	0.54
Ba	0.02	0.03	0.02	0.03
Ca	6.68	6.62	5.97	5.80
Fe	0.62	1.27	0.48	1.13
K	2.23	2.36	2.02	2.12
Mg	2.79	2.74	2.71	2.70
Mn	0.05	0.09	0.04	0.08
Na	8.99	10.45	7.08	0.01
Zn	0.02	0.03	0.01	0.01

Phytoplankton and Chlorophyll *a*

Three measures of phytoplankton abundance were used in the Roanoke study: 1) chlorophyll *a* (µg/L), 2) phytoplankton cell density (cells/L), and 3) phytoplankton wet weight biomass (µg/L). It is worthwhile to consider all three, because they do not always closely agree, and because in the literature there are chlorophyll *a*, density, and biomass data for many freshwater and estuarine systems.

Chlorophyll *a* levels are generally less than 10 ug/liter in the lower Roanoke River and western Albemarle Sound. Between 1984 and 1991 the chlorophyll *a* concentration ranged from less than 1 to over 36 µg/L, but most values were between 4 and 7 µg/L, and values above 10-15 µg/L were rare (Figure 9, Appendix Table C-5). Station averages were mostly around 6-7 µg/L.

In 1984 chlorophyll *a* concentrations were slightly higher on average in the Roanoke River (Stations 1-12) than in Bachelor Bay (Stations 13-16) (Figure 9). The averages were mostly between 3 and 8 µg/L, and there seemed to be no clear temporal pattern. In 1985 the average riverine concentrations were again usually higher than those in the Bay (Figure 9), and were somewhat higher overall than they had been in 1984. This increase may have been due to the lower instream flow in 1985. In fact, during most of the sampling period instream flow at Roanoke Rapids was about one-half the flow in 1984.

The 1986 and 1987 chlorophyll *a* data also show a clear inverse relationship with Roanoke river flow (Figures 3 and 9). Chlorophyll *a* was relatively high in the River and western Albemarle Sound in 1986, when the river flows were relatively low (5,000 cfs or lower at Roanoke Rapids). However, in 1987, the chlorophyll *a* was mostly low (less than 5 µg/L), probably due to washout caused by higher Roanoke flows (10,000-20,000 cfs).

A total of 154 phytoplankton species was found in the 1984-1991 samples. The group showing the highest diversity was the Bacillariophyceae (diatoms) (77 species), followed by the Chlorophyceae (green algae) (42 species). In addition, there were a few representatives of other classes each year: Chrysophyceae (9 species), Dinophyceae (dinoflagellates)(9 species), Euglenophyceae (euglenophytes) (5 species), and Cyanophyceae (blue-greens) (2 species). In addition there were species which could not be identified and therefore were placed in the 'Unknown' category (10). A listing of the species found through 1986 is given in Rulifson et al. (1988).

Most of the phytoplankton cell types occurred infrequently, but there were a few which were very common. Only 24 of the cell types appeared in more than 10% of the samples (Table 8). Representatives of two classes - Bacillariophyceae (diatoms) and Chlorophyceae (green algae) - dominate this list. In 1984 the most common type was *Schizogonium murale*, a green alga present in 89% of the samples. Another chlorophyte, a species of *Stichococcus*, was in 57% of the samples. Other common green algae included a species of *Zygnema* and a tiny

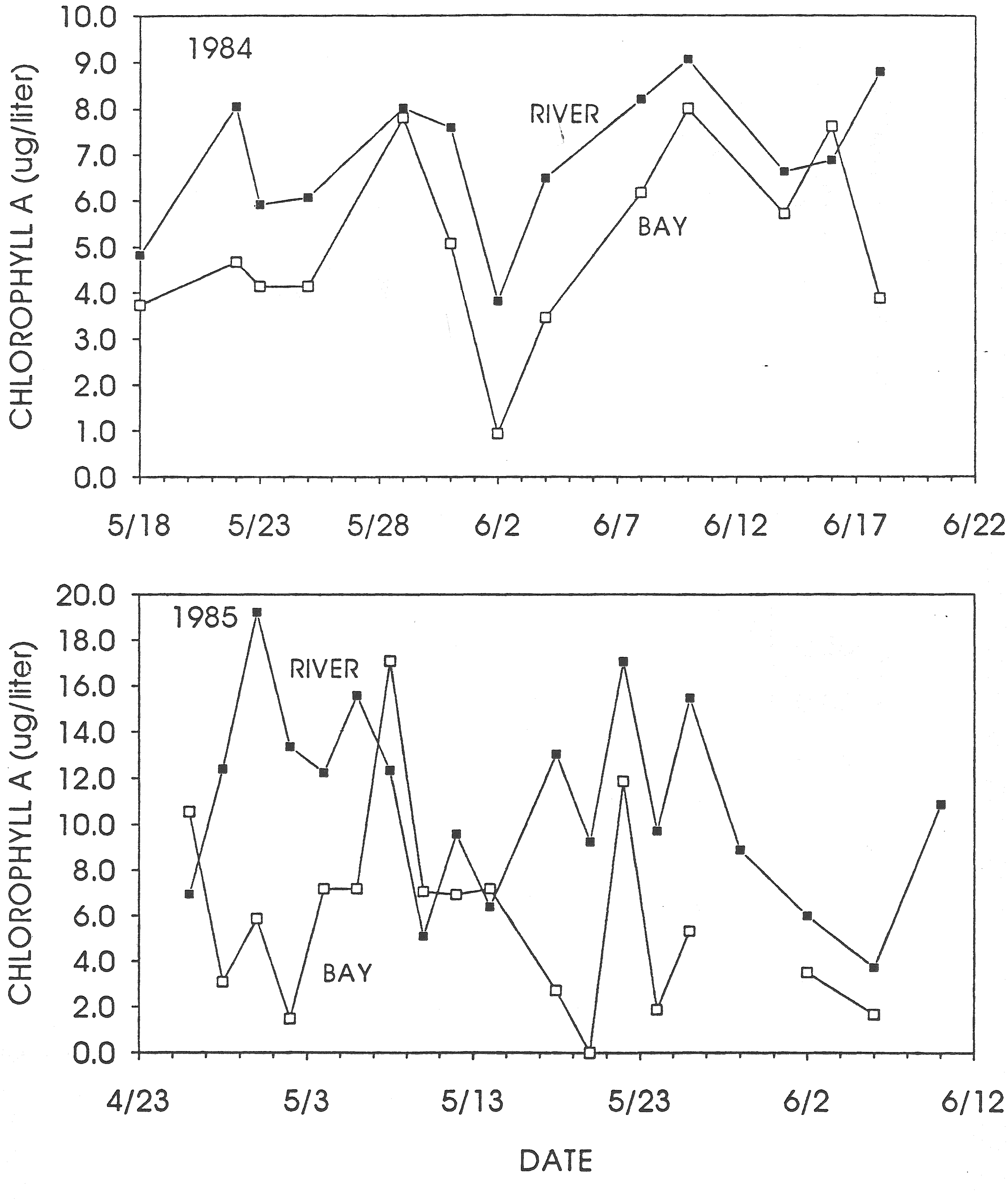
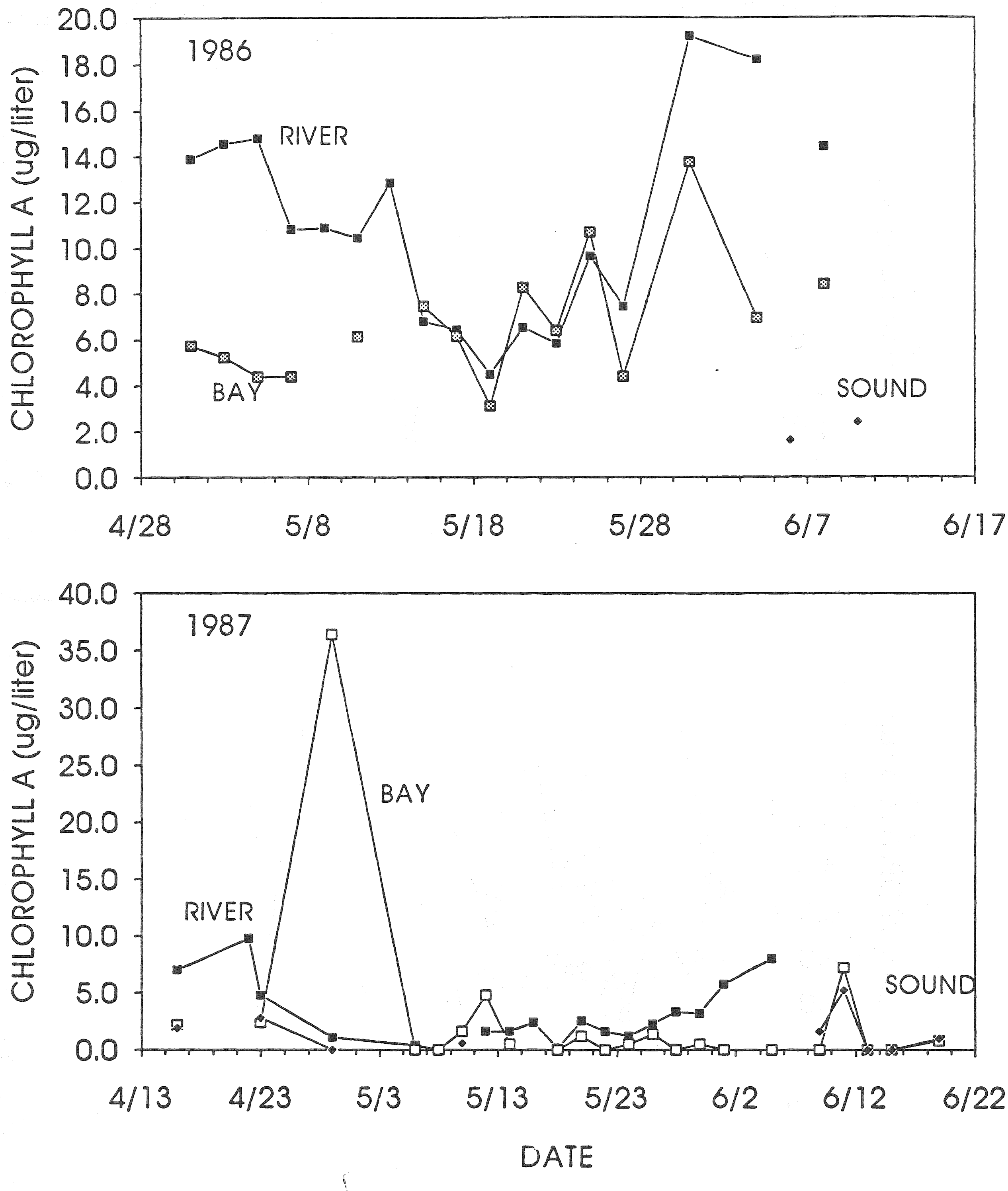


Figure 9. Average values of chlorophyll *a* (μg/L), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.



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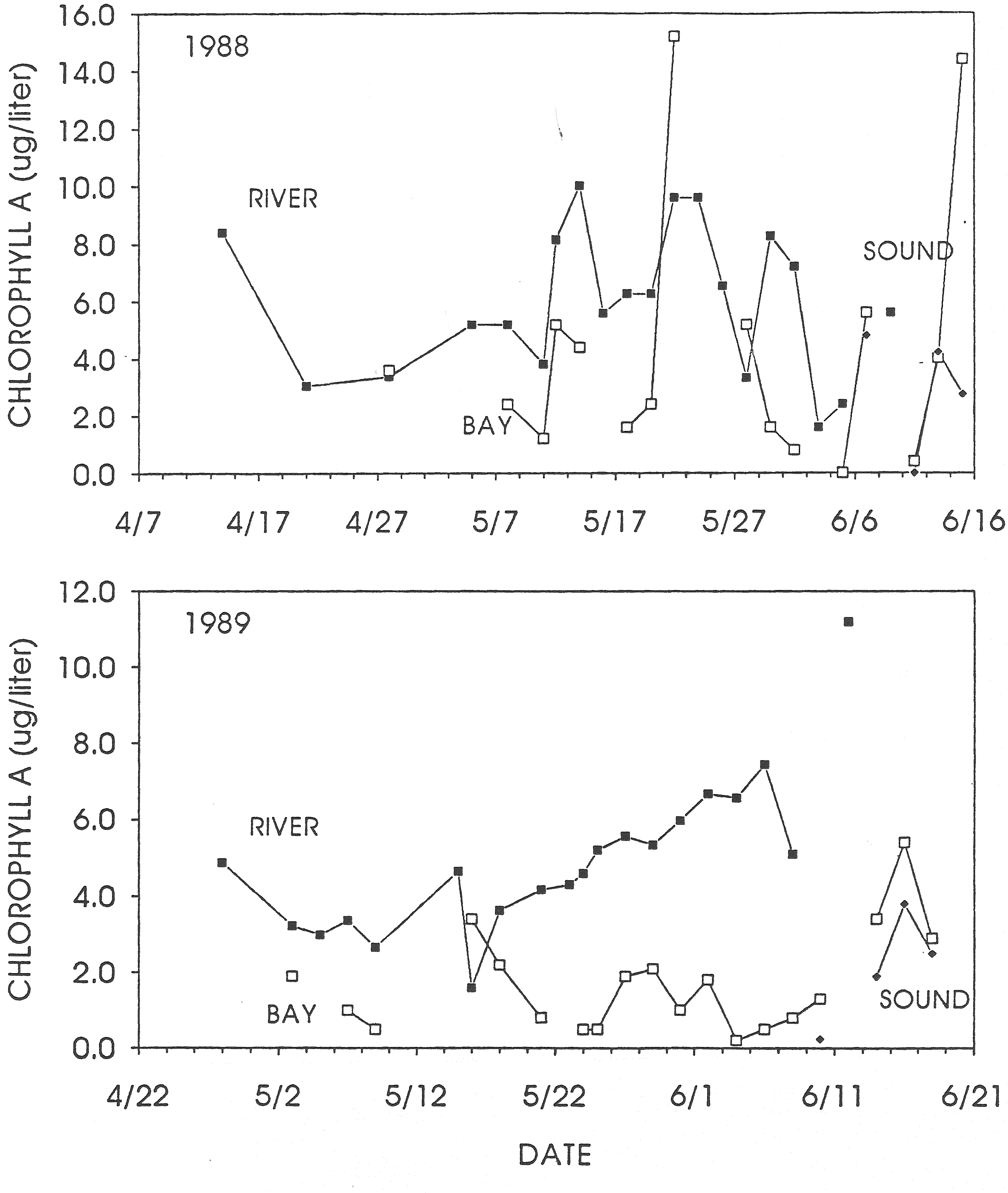

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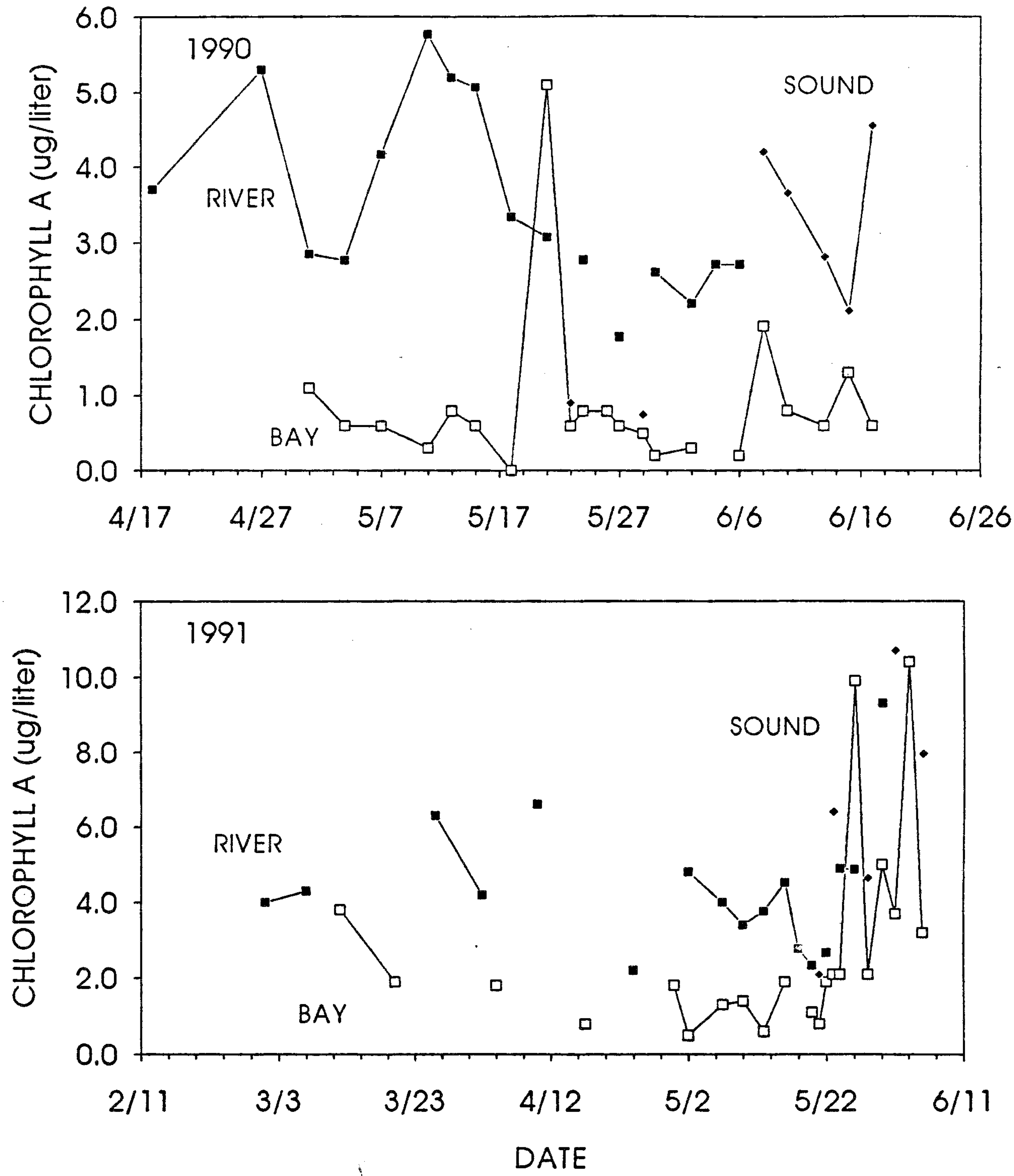


Figure 9. (continued).

Table 8. Most frequently occurring phytoplankton taxa, and their relative occurrence in samples (%), in the lower Roanoke River and western Albemarle Sound, North Carolina, between 1984 and 1991. Class BAC = Bacillariophyceae; CHL = Chlorophyceae; CHR = Chrysophyceae; EUG = Euglenophyceae; UNK = Unknown.

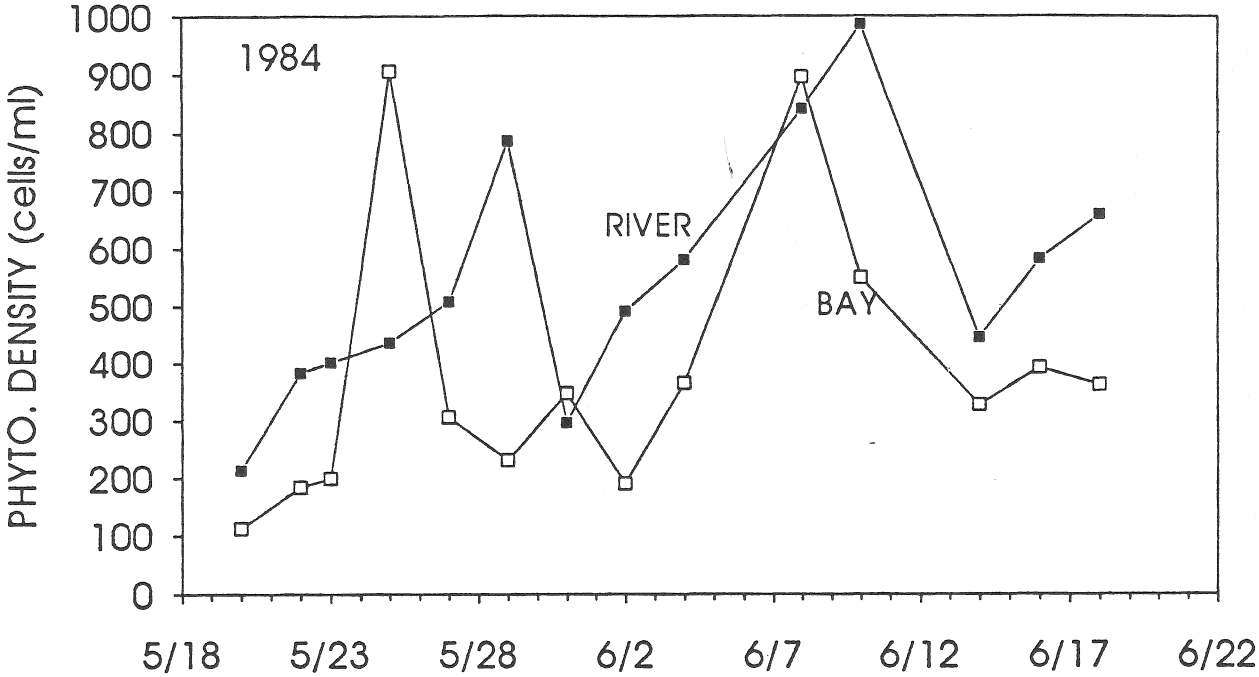
Taxon	Cell type	Class	1984	1985	1986	1987	1988	1989	1990	1991
Schizogonium murale	24	CHL	89	96	93	17	10	12	13	15
Stichococcus sp.	41	CHL	57	.	.	.	.	.	.	.
Cyclotella sp.	72	BAC	56	24	38	3	7	11	12	8
Trachelomonas sp.	327	EUG	42	.	.	.	.	.	.	.
Zygnema sp.	462	CHL	32	24	.	5	4	.	3	2
Unknown 140	140	UNK	25	.	.	.	.	.	.	.
Unknown 478	478	CHR	24	.	.	.	.	.	.	.
Unknown 464	464	CHR	22	.	.	.	.	.	.	.
Coscinodiscus sp.	468	BAC	21	.	21	.	.	3	5	5
Mallomonas sp.	465	CHR	18	.	.	.	.	.	.	.
Melosira granulata	508	BAC	.	98	84	22	.	15	15	6
Unknown 407	407	UNK	.	83	34	.	.	.	.	.
Unknown 460	460	UNK	.	71	83	14	8	9	9	5
Synedra sp. 3	509	BAC	.	59	.	3	12	6	5	6
Fragilaria sp. 4	511	BAC	.	41	.	2	3	.	3	.
Actinastrum hantzchii	49	CHL	.	23	.	.	.	.	.	.
Fragilaria sp. 3	463	BAC	.	21	37	.	.	.	11	.
Calycomonas ovalis	300	CHR	.	.	.	57	3	.	.	.
Unknown 502	502	UNK	.	.	.	30	.	.	10	8
Zygnema sp.	462	CHL	.	.	29	.	4	.	.	.
Unknown 6	6	UNK	.	.	.	.	7	.	.	.
Cyclotella sp.	3	BAC	.	.	.	.	3	3	.	4
Unknown 313	313	BAC	.	.	.	.	5	3	.	.
Navicola sp. 14	104	BAC	.	.	.	.	.	3	.	6

unidentified species (Unknown #127). The most common diatom was a species of *Cyclotella* (cell type 72), which was in 56% of the samples. *Coscinodiscus*, *Diploneis*, *Navicula*, and *Cyclotella* (cell type 3) were other genera of diatoms represented in 10-20% of the samples. *Trachelomonas*, a euglenophyte, was in about one-half the samples (42%), and a species of *Euglena* was in 12.6% of the samples. Three species of chrysophytes, including *Mallomonas*, were fairly common. In 1985 the most common types were *Melosira granulata*, a diatom that was in 98% of the samples, and *Schizogonium murale*, present in 96% of the samples. *Synedra, Fragilaria, Cyclotella, Coscinodiscus*, and *Diploneis*, were the other genera of diatoms represented in 10% or more of the samples. These genera continued to dominate the phytoplankton community throughout the study period. However, in the latter years, especially from 1989 on, they were not as common as in the earlier years. The reason for this decrease in the frequencies of occurrence is unknown.

Phytoplankton cell densities ranged widely, from less than 100 cells/ml to over 10,000 cells/ml in a few samples, but values in the range 500-3,000 were most common (Appendix C-1, C-3). In most years, the densities were highest early in the sampling period, and tended to decline later. For example, in 1985, the early season values were over 10,000 cells/ml (average) in the Roanoke River, but declined drastically to less than 2,000 cells/ml by early June (Figure 10). Concentrations of algae in the Bachelor Bay region followed the same temporal pattern, but overall were lower than in the river. The same pattern can be seen clearly in the 1986 data, and to a lesser degree in the 1987-1991 data (Figure 10). An exception to this pattern occurred in 1984, when average densities in the Roanoke River gradually rose from around 200 cells/ml in mid-May to nearly 1000 cells/ml by 12 June, before falling back to around 600 cells/ml later in the month (Figure 10). Except for peaks in late May, the 1984 densities were mostly less than 500 cells/ml.

Biomass of the phytoplankton (µg wet weight/L) also was highly variable, but there were some trends. For most samples the biomass fell between 300 and 800 µg/L, but was extremely low or high on a few occasions. For example, at Station 14 on 18 May and 31 May, 1984, the values were less than 10 µg wet weight/L. Unusually high biomass values (greater than 10,000 µg wet weight/L) were measured in a few samples, and were the result of either very high densities of average-sized cells (e.g., 27 May 1984), or relatively low densities of very large phytoplankters (e.g., 31 May 1984) (Appendix C-4).

In most years, phytoplankton biomass showed about the same temporal and spatial patterns as algal cell density. For example, in 1985, biomass varied from 2-11,605 µg wet weight/L), but most values ranged between 500 and 2000 µg wet weight/L. Over time the average biomass for all stations declined from 1500-3400 µg wet weight/L early in the sampling period to around 400-700 µg wet weight/L in early June. In the Roanoke, algal biomass did not show as much spatial variability as algal cell density. In the Bay, however, the biomass, like cell density, was considerably lower than in the Roanoke (Figure 11).



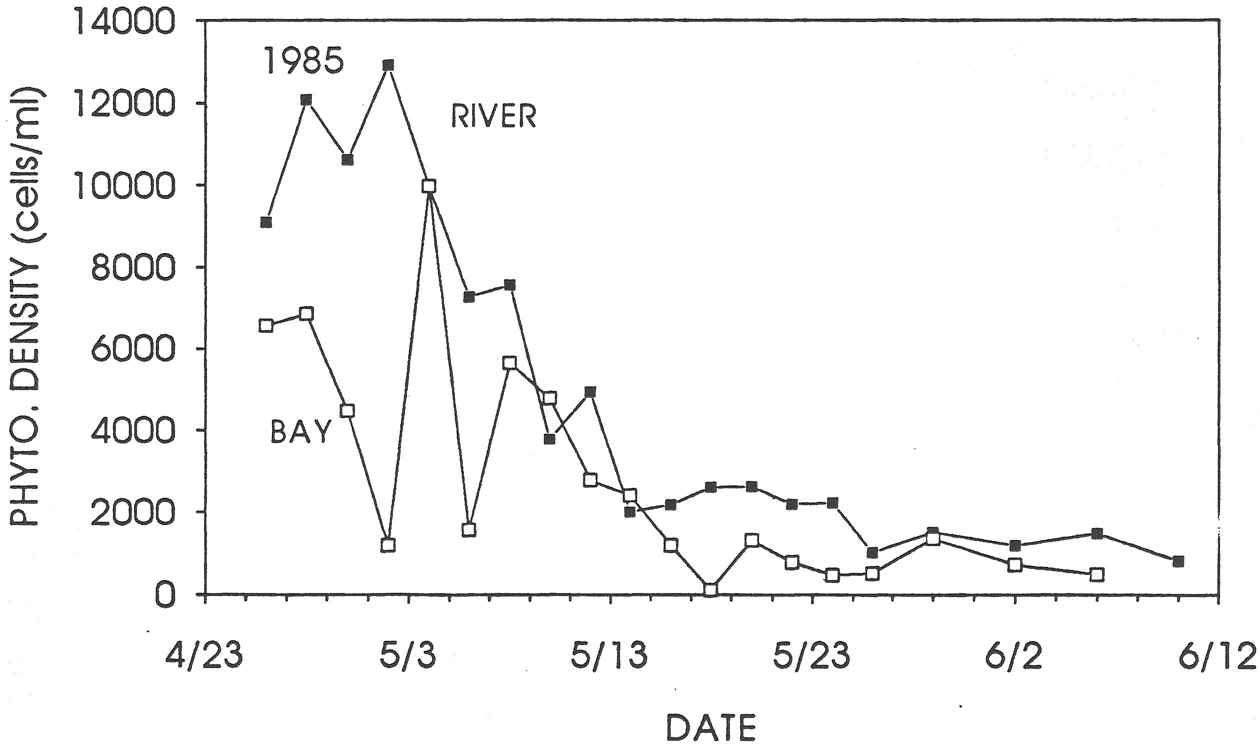


Figure 10. Average phytoplankton density cells/ml), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.

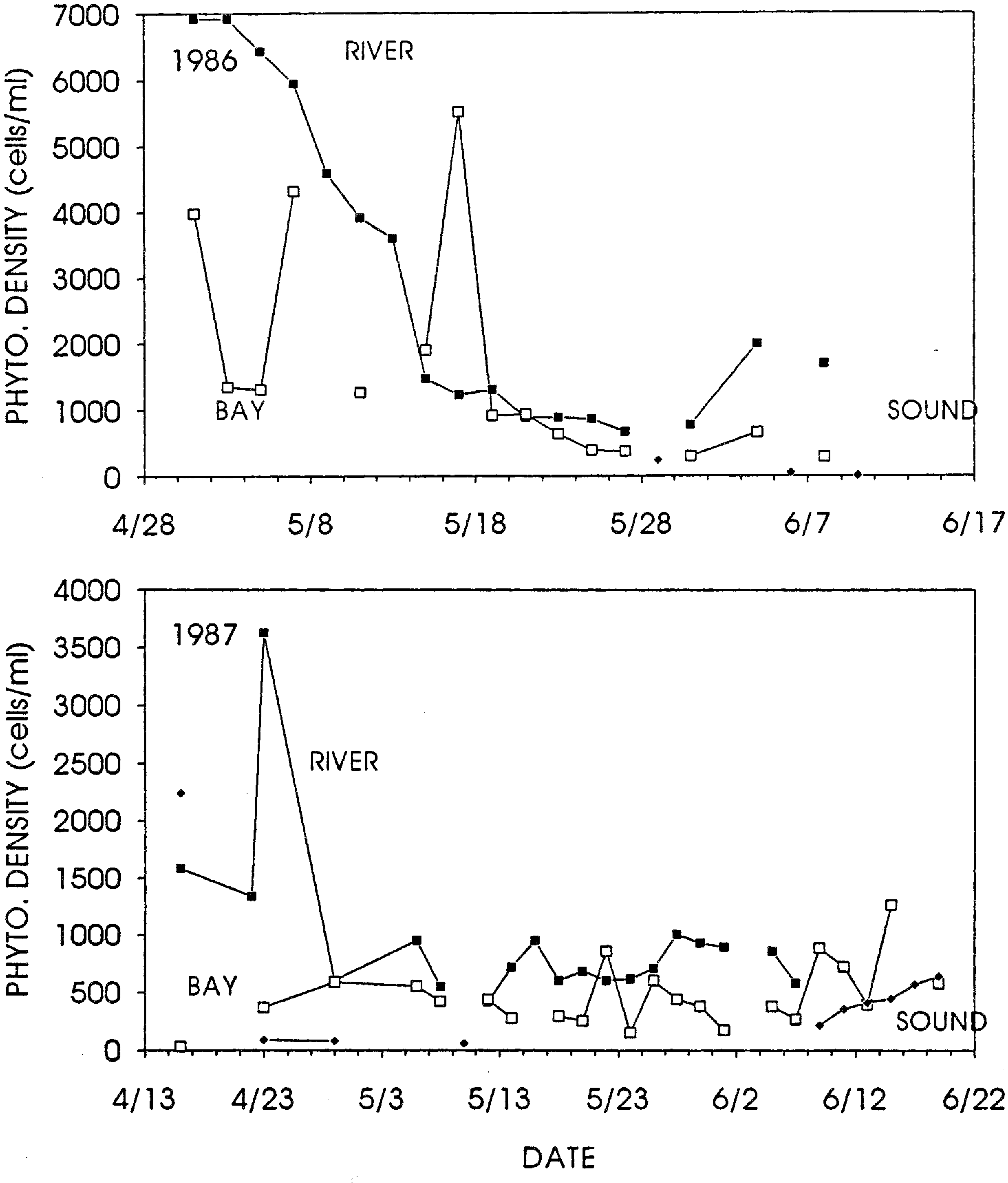


Figure 10. (continued).

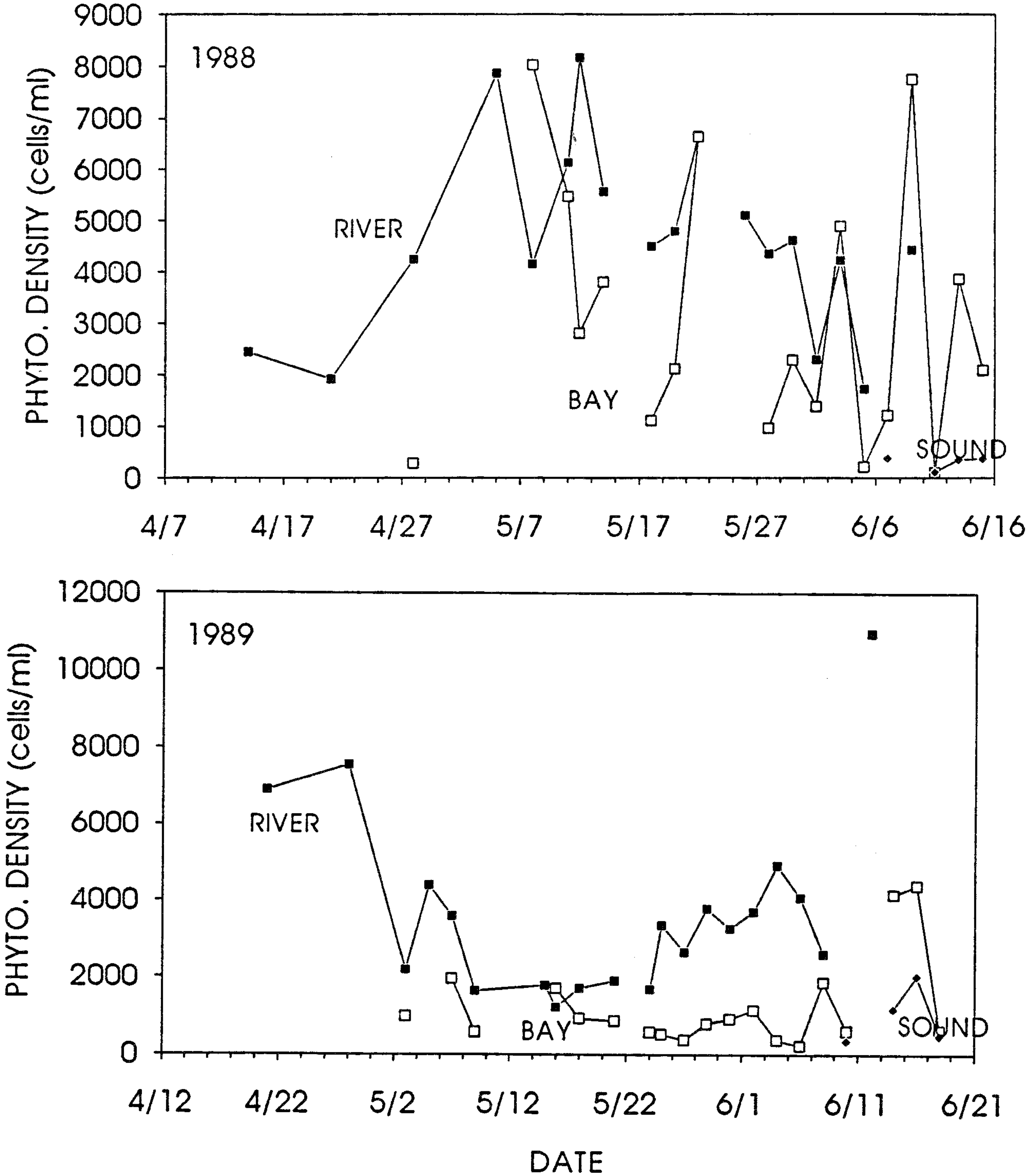
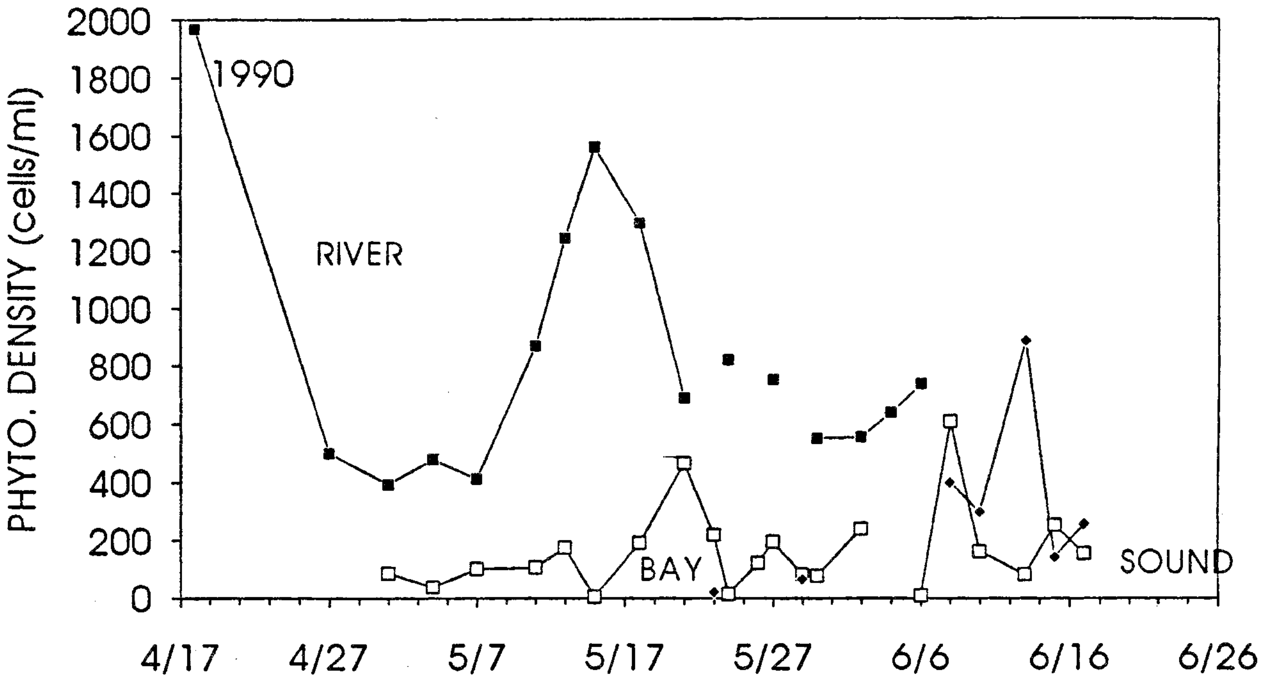


Figure 10. (continued).



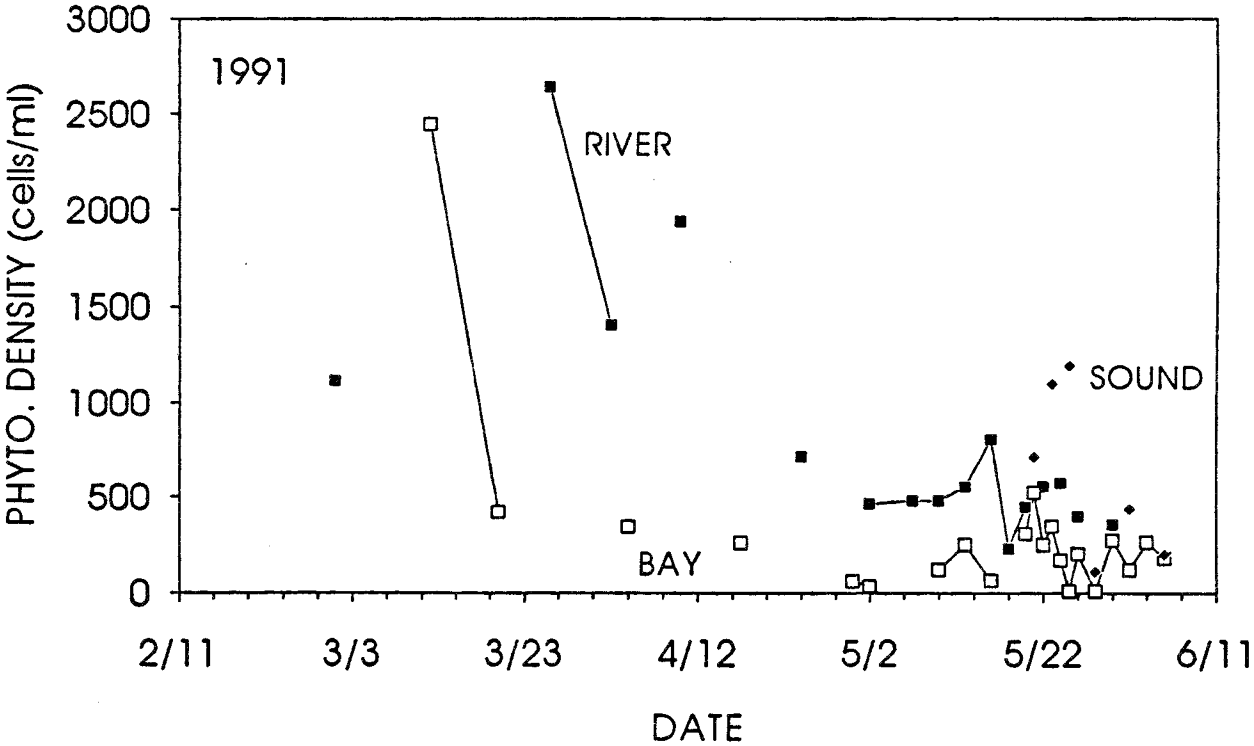


Figure 10. (continued).

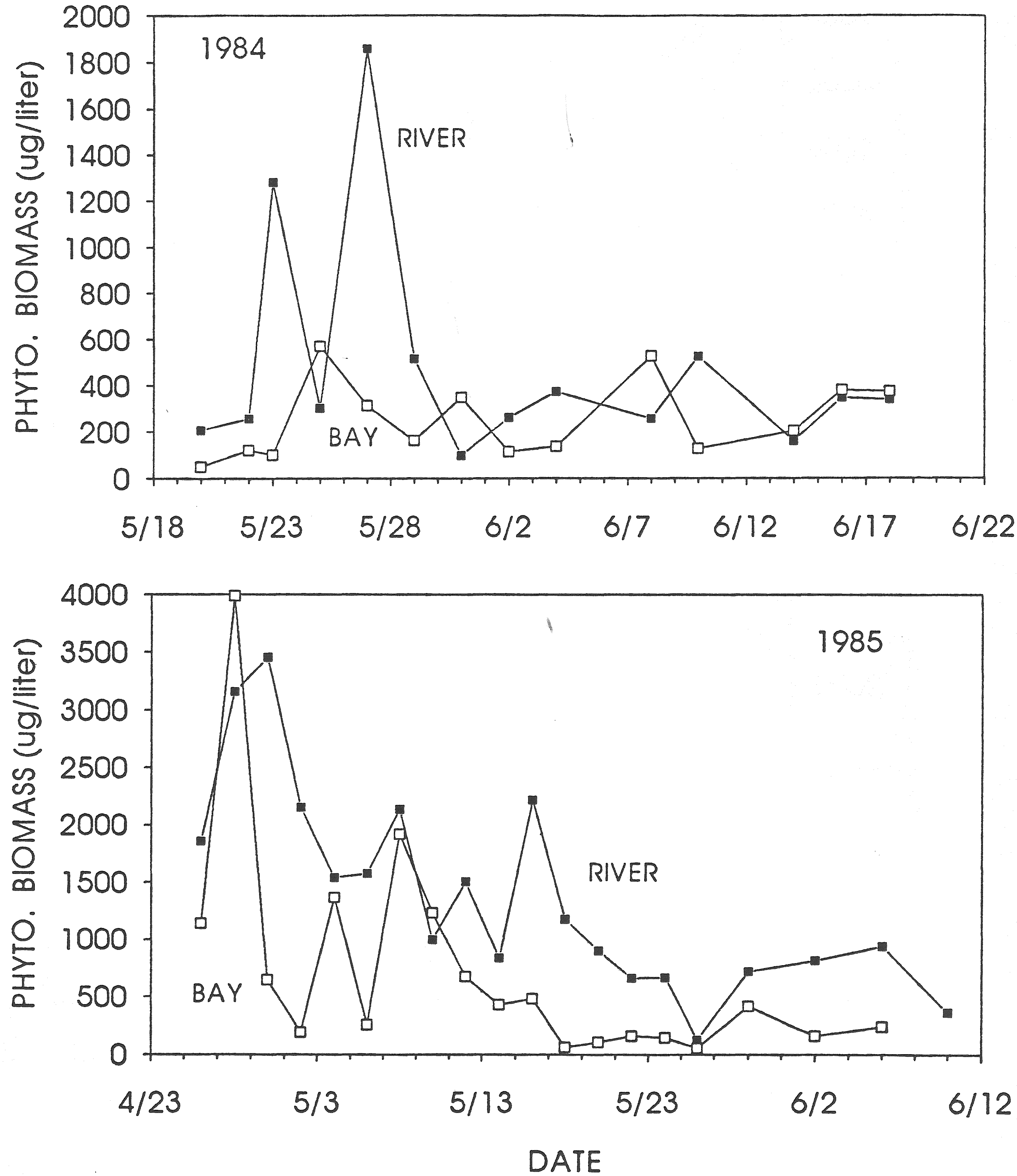


Figure 11. Average phytoplankton biomass (µg/L), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.

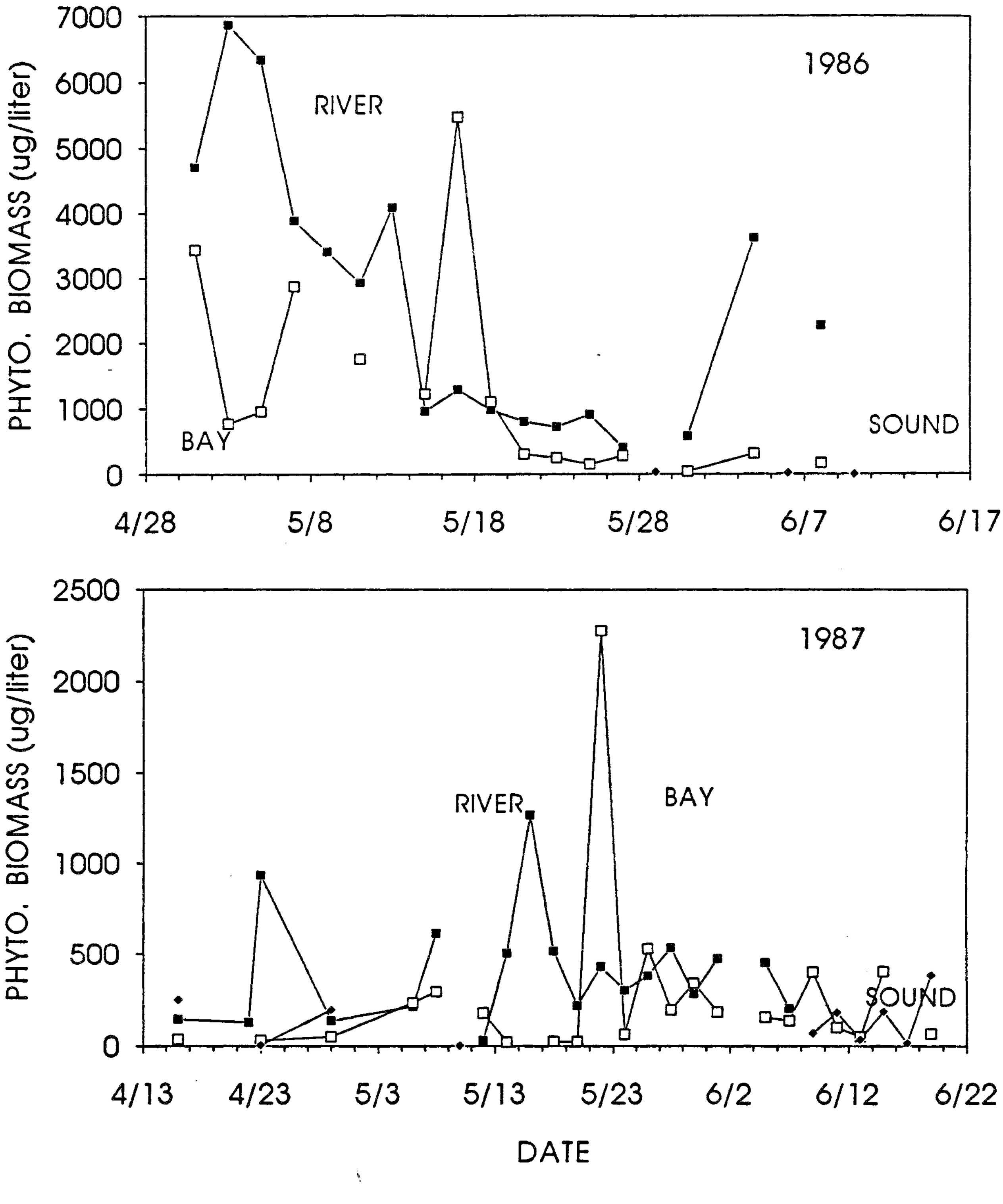


Figure 11. (continued).

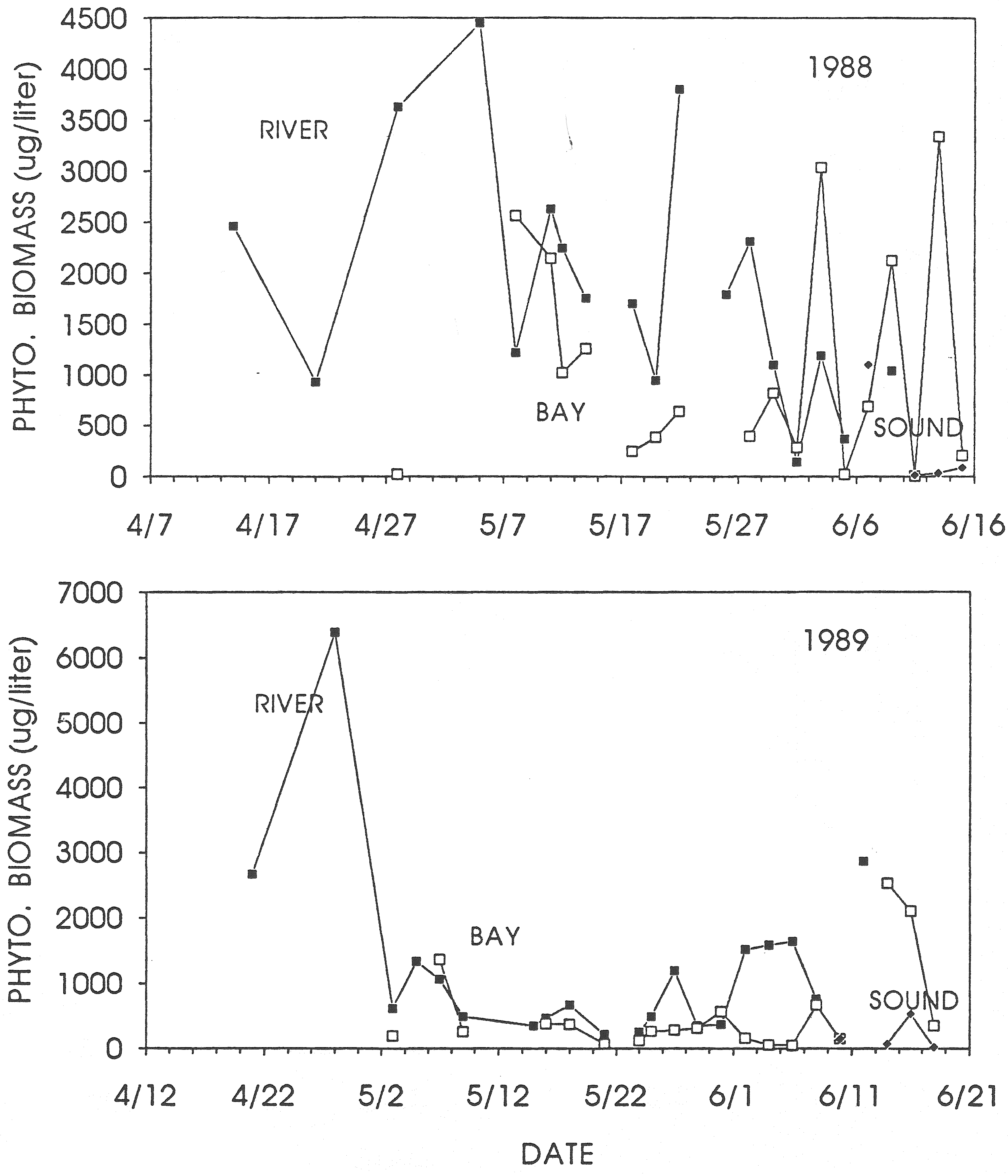


Figure 11. (continued).

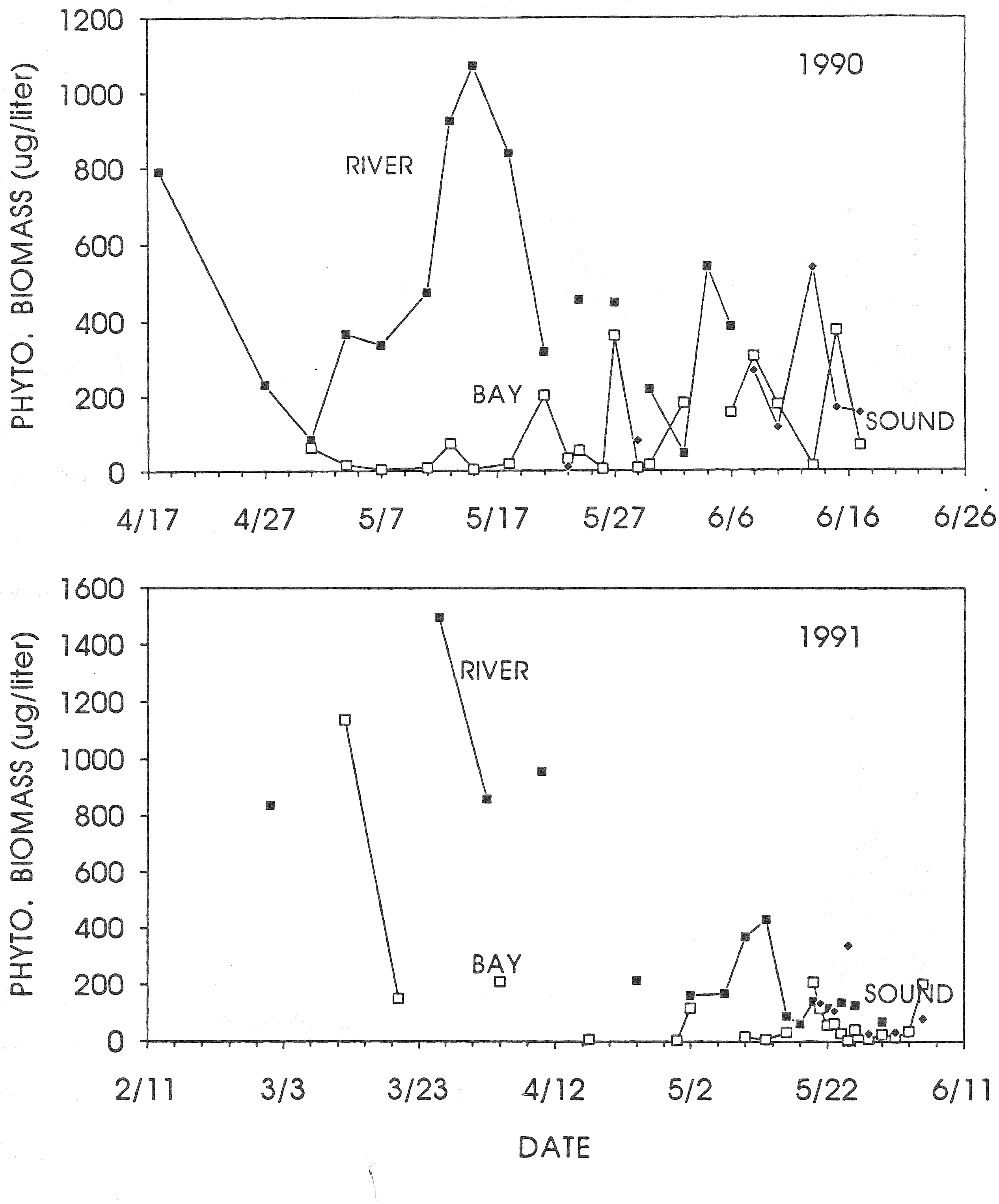


Figure 11. (continued).

Cell densities and biomass for the various algal taxonomic groups was computed and presented in earlier reports covering the three years when the phytoplankton sampling was most intensive (1984-86) (see Rulifson et al. 1986a; Rulifson et al. 1988). Those computations showed that in 1984 green algae (Chlorophyceae) were the most numerous type at all the stations, making up from 47-87% of the average cell density (74% average). The second most important group was the Chrysophyceae, which comprised from 3-33% of the total cell density (13% average). Diatoms (Bacillariophyceae) made up about 3-5% of the total cell density at all stations except 18, where they comprised about 15% of the total. Dinophyceae and Euglenophyceae were present, but not abundant, in some samples. Overall, green algae were predominant, making up about 44% of the total biomass on average. Diatom and chrysophyte biomass each averaged about 15% of the total, and dinoflagellates and euglenophytes each contributed a minor fraction to the total biomass at some stations. There were no obvious spatial or temporal patterns in this algal class distribution data (Rulifson et al. 1986).

Cell density and biomass patterns for the various algal classes were very different in 1985 from those in 1984. The major change in relative abundance, as measured by cell density, was the replacement of green algae by diatoms as the major class. In 1985 diatoms comprised the majority of the total cell density (between 51% and 73%). On the other hand green algae were less important in 1985; they averaged only about 25-30% of the total cell density at most stations. Chrysophyceae also were relatively less important in 1985 than in 1984. As in 1984, Dinophyceae, Euglenophyceae, and Unknowns comprised small percentages of the total cell density. The diatoms were also a larger percentage of the total biomass in 1985 than in 1984. At most stations they averaged between 40% and 60% of the total. Green algae, the second most important group in terms of biomass, made up 20-40% of the total.

Finally, in 1986, diatoms and green algae made up from 70-to-90% of the total algal community (in terms of density). In the lower Roanoke and in the Bay, the numbers of green algae and diatoms were about equal; each group accounting for approximately 40% of the total cell density. Farther out in western Albemarle Sound, the diatoms were relatively more important than the green algae. In terms of wet weight biomass, the overall pattern was the same as for cell density. Thus, in summary, while there is year-to-year variability, the Roanoke phytoplankton is clearly dominated by green algae (Class Chlorophyceae) and diatoms (Class Bacillariophyceae).

Small phytoplankters make up most of the Roanoke biomass. For example, in 1984, about two-thirds of the species were less than 10 µm in diameter (spherical equivalents), and 97% (all but 2) were less than 20 µm diameter. There were more larger species in 1985, but still, 80% were less than 20 µm diameter. The smaller cells, less than 10 µm diameter, were the most numerous in both years (91-94% of total), while 5-20 µm diameter cells accounted for around 90% of the total biomass in both years (Rulifson et al. 1986).

Zooplankton

The patterns of zooplankton abundance and distribution in the lower Roanoke River, Batchelor Bay, and western Albemarle Sound are different each year (Figure 12). In general, the abundance of zooplankton was lower than for other river systems supporting spawning populations of striped bass. It was not uncommon for zooplankton densities to average 600-1,000 individuals/m^3. Occasional (relatively) high values were observed, the causes of which usually were attributable to the abundance of one zooplankton taxonomic group. For example, higher values of River and Bay zooplankton abundance in late April of 1985 (Figure 12) were caused by increased populations of *Bosmina, Daphnia*, and cyclopoid copepods (Appendix Tables D-2 and D-3). Relatively high and short-term abundance of zooplankton observed in mid-April of 1987 was most likely caused by *Bosmina* and other cladocerans being flushed out of the floodplain areas by the record-setting 35,000 cfs discharge from the reservoirs at the time (Figure 3, Appendix Table D-2). A brief abundance peak evident in 1991 was caused by increased abundance of the same taxonomic groups observed in 1985 (Figure 3).

Zooplankton abundance is not uniform throughout the watershed, but typically is concentrated in several areas. Within the Roanoke River delta, the Cashie River consistently has the greatest zooplankton abundance . Station 8 in the Cashie River and Station 11 at the Cashie River mouth averaged 1,043 individuals/m^3 and 869/m^3, respectively, for the eight-year study (Table 9). Station 9 in the lower Middle River and Station 10 in the Roanoke main stem also had greater abundance on average than locations farther upstream. In Batchelor Bay, Station 16 along the western shore typically had the highest zooplankton concentration, and in western Albemarle Sound zooplankton were most abundant at Stations 22-24 near Edenton Bay along the north shore (Table 10, Figure 2).

The zooplankton community resembles that of a freshwater community in this oligohaline estuary, but the species composition of the community changes from the River through the Bay into the western Sound. For the period of study, cladocerans dominated the River zooplankton community representing about 55% of the individuals. Dominant cladocerans were *Daphnia* (16.3%) and *Bosmina* (9.0%). The other dominant taxonomic group in the River was copepods (33.7%), primarily cyclopoids (24.3%) and to a lesser extent calanoids (5.7%) and harpacticoids (3.0%). Batchelor Bay is a region of transition for the zooplankton community. Cladocerans still dominate the community (48.7%). *Leptodora*, a predatory cladoceran seldom oberved in river samples, represented 1.6% of all Bay zooplankton. Copepods increased in importance (nearly 41%), with both cyclopoids (26.3%) and calanoids (11.1%) comprising a greater number of individuals (Table 11). Gammarid amphipods were most abundant in Batchelor Bay representing 3.9% of the zooplankton density. In the western Sound, copepods were the dominant group representing over 75% of the zooplankton community. The remainder of the community was mostly cladocerans (21%), with *Leptodora* representing the dominant genus of the group (Table 11).

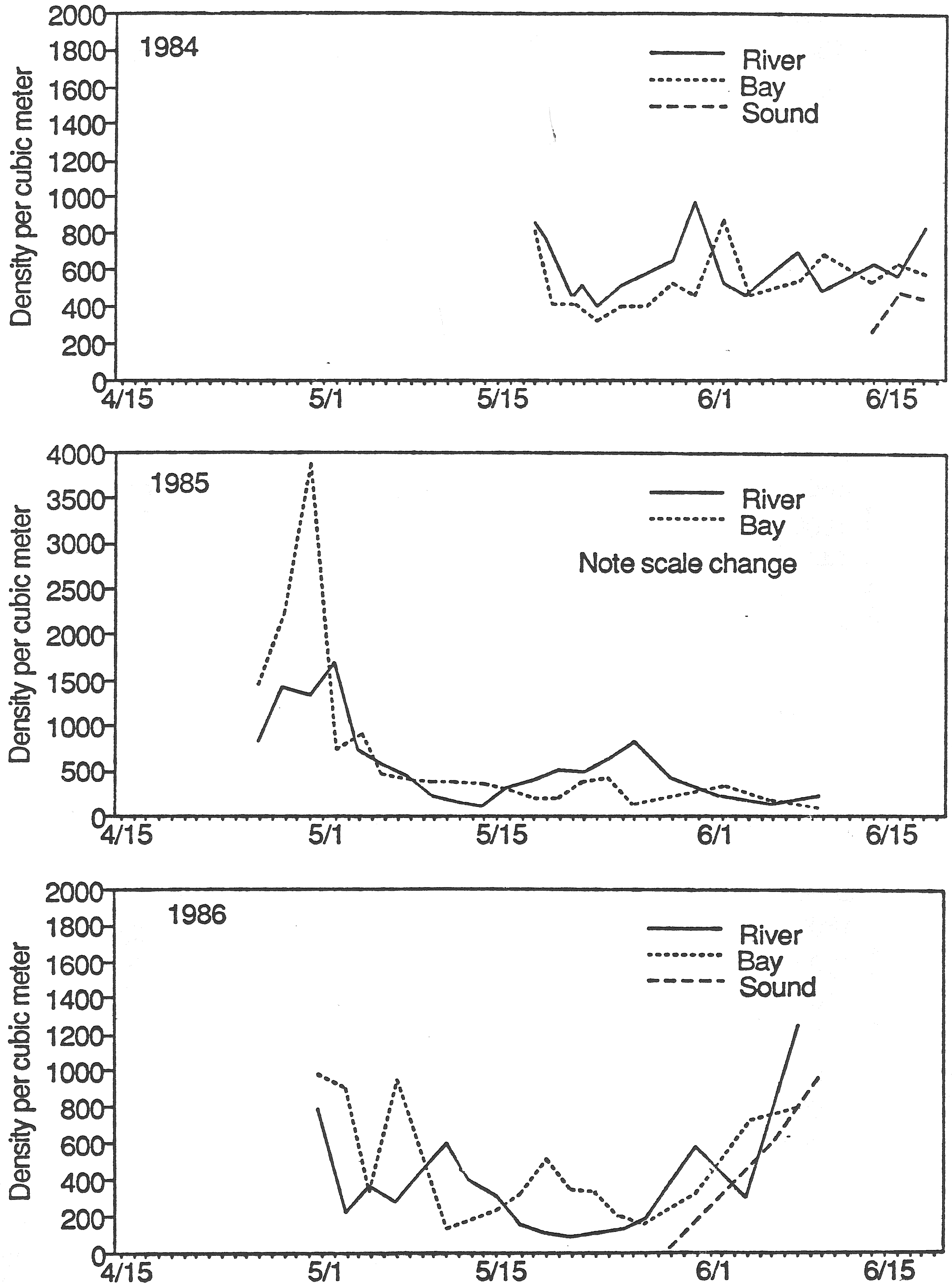


Figure 12. Average zooplankton density (number/m^3), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.

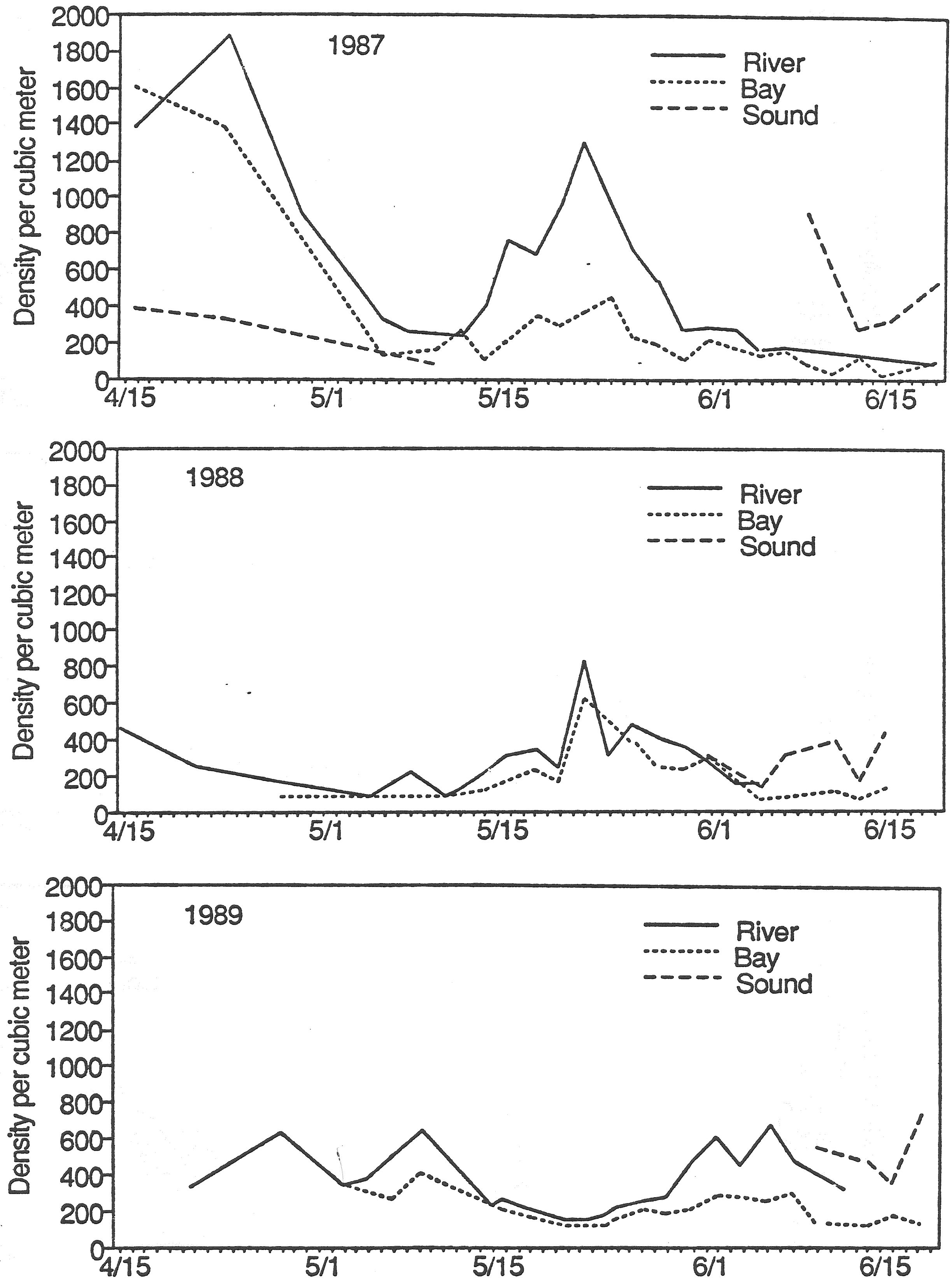


Figure 12. (continued).

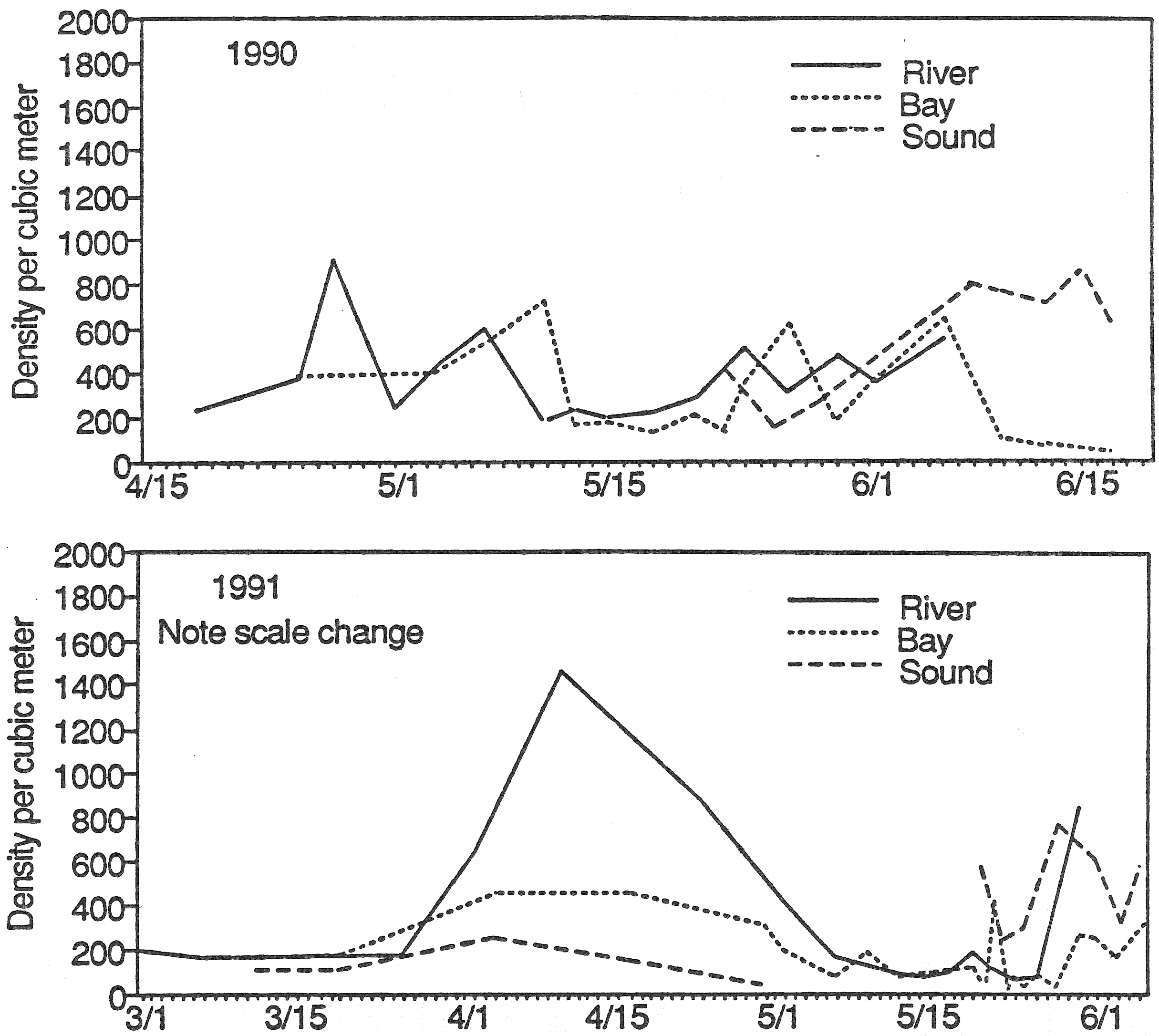


Figure 12. (continued).

Table 9. Average density (/m^3) of zooplankton taxa, by station, in nighttime samples collected in the lower Roanoke River (Stations 1-4, 7, 10, 12), Middle River (Stations 6 and 9), and Cashie River (Stations 8 and 11), North Carolina, for the period 1984-1991.

PERIOD=N	STATION												
TAXONOMIC GROUP	1	2	3	4	5	6	7	8	9	10	11	12	AVE.
Amphipoda - gammarid egg	.	.	.	.	.	.	.	0	0	.	0	.	0
Amphipoda - Gammaridae	0	0	0	1	1	1	1	3	3	1	7	2	2
Arachnida	1	1	1	1	1	1	1	1	1	1	1	1	1
Arachnida - tick	.	.	.	.	.	.	.	.	.	.	0	.	0
Bivalvia	0	1	0	0	0	0	0	0	0	0	0	.	0
Bivalvia - larv.	0	0	0	1	.	0	0	0	0	1	.	0	0
Caddisfly adult	.	.	0	.	0	.	.	0	.	.	.	.	0
Caddisfly larv.	0	0	0	0	0	0	0	0	0	0	0	0	0
Clad.- Bosmina	47	17	13	32	22	41	30	64	56	30	45	36	36
Clad.- Daphnia	64	56	44	60	53	66	66	112	59	55	92	76	67
Clad.- Leptodora	0	0	0	.	0	0	0	0	0	0	1	0	0
Cladocera - other	148	160	95	115	131	116	92	147	157	103	145	91	125
Cladocera - unid. egg	0	0	0	0	0	0	0	1	2	1	0	0	0
Cladocera - unid. juv.	0	1	1	1	1	1	1	3	2	1	2	1	1
Coleopt.-Dytiscidae larv.	.	.	.	0	0	0	0	0	0	0	0	0	0
Coleopt.-Gyrinidae adult	.	0	0	.	.	0	0	0	0	0	0	0	0
Coleopt.-Gyrinidae larv.	.	0	0	0	0	0	0	0	0	0	0	0	0
Coleopt.-Peltodytes larv.	.	.	.	.	.	0	.	.	.	.	.	.	0
Coleoptera	0	0	1	0	1	0	1	0	0	0	0	0	0
Coleoptera - Elmidae	.	0	.	.	.	0	0	.	.	.	.	.	0
Collembola larv.	0	0	.	0	0	0	0	0	0	0	0	0	0
Copepoda - egg mass	.	.	.	0	0	0	0	1	0	0	1	.	0
Copepoda - nauplius	0	0	0	0	0	0	0	0	0	0	0	.	0
Copepoda - Calanoida	24	16	24	14	22	17	10	56	19	11	50	18	24
Copepoda - Cyclopoida	75	50	48	55	64	72	60	282	92	52	224	80	96
Copepoda - Harpacticoida	2	2	1	2	6	6	6	53	10	6	34	5	11
Copepodids	2	2	3	2	1	4	3	4	3	2	3	2	3
Decapoda - shrimp larv.	.	.	.	.	.	.	0	.	.	.	.	.	0
Dipt.-biting midge larv.	0	0	0	0	0	0	0	0	0	0	0	0	0
Dipt.-biting midge pup.	0	.	.	0	.	.	.	.	.	.	.	.	0
Dipt.-chironimid pup.	0	0	0	0	0	0	0	0	0	.	0	0	0
Dipt.-chironomid adult	0	0	0	0	0	0	0	0	0	0	0	0	0
Dipt.-chironomid larv.	2	3	3	2	4	2	2	2	2	1	4	2	2
Dipt.-mayfly adults	.	.	.	.	.	.	.	.	.	0	.	.	0
Dipt.-mayfly nymphs	0	0	0	0	0	0	0	0	0	0	0	0	0
Dipt.-mosquito adult	.	.	0	0	0	0	.	0	0	.	0	0	0
Dipt.-mosquito larv.	.	0	0	0	0	0	0	0	0	0	.	.	0
Dipt.-mosquito pup.	.	.	.	0	0	0	0	0	.	0	0	0	0
Dipt.-phantom midge adult	0	.	0	.	.	.	.	0	.	.	0	0	0
Dipt.-phantom midge larv.	0	0	0	0	2	0	1	7	1	1	4	1	2
Dipt.-phantom midge pup.	0	0	0	0	0	0	0	1	1	0	1	0	0
Dipt.-Dixidae adult	.	0	.	.	0	.	.	.	.	.	.	.	0
Diptera	0	0	0	0	0	0	.	0	0	0	0	0	0
Gastropoda - egg	0	.	.	.	.	.	.	.	.	.	.	.	0
Gastropoda - snail	0	0	0	0	0	.	0	.	0	0	0	0	0
Hemiptera	0	0	0	0	0	0	.	.	.	0	0	0	0
Hemiptera - Corixidae	.	.	0	.	0	.	0	.	.	.	.	.	0

Table 9. Average River zooplankton density (continued).

PERIOD=N	STATION												
TAXONOMIC GROUP	1	2	3	4	5	6	7	8	9	10	11	12	AVE.
Hemiptera-Belostomatidae	.	.	.	.	.	.	.	.	0	.	.	.	0
Hirudinea	0	.	.	0	0	0	0	.	0	0	0	.	0
Hydra	15	10	5	4	3	2	2	1	2	2	2	2	4
Hydra - medusa	0	0	0	.	0	0	0	.	.	0	.	.	0
Hymenoptera - ant	0	0	.	.	0	.	.	.	0	.	0	.	0
Hymenoptera- diving wasp	0	0	0	0	.	0	0	0	0	0	0	0	0
Hymiptera - Gerridae	.	0	.	.	.	.	.	.	.	.	.	.	0
Isopoda	.	.	0	.	0	0	0	.	.	0	0	0	0
Megalopt.-alderfly larv.	0	.	.	.	.	0	.	.	.	.	.	.	0
Mysidacea - Mysis shrimp	.	.	.	.	.	.	.	.	.	.	0	.	0
Mysidacea - Mysis zoea	0	.	.	.	.	.	.	.	.	.	.	.	0
Nematoda	0	0	0	0	0	0	0	0	0	0	0	0	0
Odonata	0	.	.	.	0	0	.	0	0	0	0	0	0
Oligo.- Aeolosoma	3	2	1	1	1	0	1	0	1	1	0	0	1
Oligo.- Dero	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligo.- Stylaria	0	0	1	1	1	1	1	1	1	1	2	1	1
Ostracoda	2	2	3	3	5	8	5	50	17	5	45	6	13
Plecoptera adult	.	.	.	.	0	.	.	.	0	.	.	.	0
Plecoptera nymph	0	0	0	.	.	0	.	.	.	0	.	0	0
Polychaeta	0	0	0	0	0	0	0	0	.	0	0	.	0
Rotifer - colonial	1	2	3	2	1	1	1	1	1	1	1	1	1
Rotifer - single	30	8	3	8	2	1	11	37	1	6	43	2	13
Spongillafly adult	0	0	0	0	0	0	0	0	0	0	0	0	0
Spongillafly larv.	0	0	0	0	.	0	0	0	0	0	0	0	0
Tanaid	.	.	.	.	.	.	.	.	.	.	.	0	0
Tardigrada	0	.	.	.	.	.	0	.	.	0	.	.	0
Thysanoptera (thrip)	0	0	0	0	0	0	.	0	0	.	.	0	0
Tubellaria	.	.	.	0	.	.	.	.	.	.	.	.	0
Unidentified	1	1	2	1	3	1	2	1	1	1	2	1	1
Worms	.	.	.	.	.	.	.	.	.	0	.	.	0
Total density (/m3)	420	335	256	311	328	345	297	1043	624	617	869	329	481
Avg. volume sampled (m3)	21	22	21	22	21	27	27	26	27	26	26	26	24
(n) Dates sampled	91	84	81	86	101	119	117	133	127	135	116	119	1309

Table 10. Average density (/m^3) of zooplankton taxa, by station, in nighttime samples collected in Batchelor Bay (Stations 13-16) and western Albemarle Sound (Stations 17-32), North Carolina, for the period 1984-1991.

PERIOD=N	STATION																
TAXONOMIC GROUP	13	14	15	16	17	18	20	21	22	23	24	26	28	31	32	AVE1	AVE2
Amphipoda - gammarid egg	0	.	0	0	.	.	.	.	.	0	.	.	.	.	.	0	0
Amphipoda - Gammaridae	13	23	16	11	6	7	3	12	1	2	2	2	8	8	2	16	5
Arachnida	1	1	1	1	2	0	0	0	0	1	0	0	0	1	0	1	1
Bivalvia	1	.	0	0	.	0	0	.	0	.	.	.	.	0	0	0	0
Bivalvia - larv.	0	.	0	0	.	.	.	.	.	.	.	.	0	.	.	0	0
Caddisfly adult	0	.	.	0	.	.	.	.	.	.	.	.	.	.	.	0	.
Caddisfly larv.	0	0	0	0	.	0	.	.	.	0	0	.	0	.	.	0	0
Clad.- Bosmina	55	77	39	25	9	26	15	8	14	14	26	25	22	9	7	49	16
Clad.- Daphnia	62	24	79	69	32	24	50	22	7	7	16	9	14	17	14	58	19
Clad.- Leptodora	4	20	4	5	97	19	10	21	65	42	50	32	31	24	61	8	41
Cladocera - other	91	86	51	47	20	31	26	17	32	35	41	19	27	16	32	68	27
Cladocera - unid. egg	0	.	0	1	.	0	.	0	.	.	1	.	.	.	.	1	0
Cladocera - unid. juv.	2	.	1	2	.	0	1	0	0	0	1	0	0	0	0	1	0
Coleopt.-Dytiscidae larv.	0	.	0	0	.	.	0	.	.	.	.	.	.	.	.	0	0
Coleopt.-Gyrinidae adult	.	0	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Coleopt.-Gyrinidae larv.	0	.	0	0	.	0	.	.	.	.	.	.	.	.	.	0	0
Coleoptera	0	0	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Collembola larv.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Copepoda - egg mass	1	.	0	0	.	0	0	0	0	0	0	0	0	0	0	0	0
Copepoda - nauplius	.	.	0	.	.	.	.	.	.	.	.	0	.	.	.	0	0
Copepoda - Argulus sp.	.	.	.	.	.	0	.	.	.	.	.	.	.	.	.	.	0
Copepoda - Calanoida	39	97	34	26	3	13	76	60	44	28	66	77	90	29	22	49	46
Copepoda - Cyclopoida	141	124	72	72	66	266	136	135	467	653	607	277	353	140	291	102	308
Copepoda - Harpacticoida	14	27	8	3	2	2	0	.	0	.	.	1	.	2	.	13	1
Copepodids	2	1	1	3	.	0	0	0	0	0	0	.	0	0	1	2	0
Cumacea	.	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.	0
Dipt.-biting midge larv.	0	0	0	0	.	0	0	0	.	.	0	0	.	0	.	0	0
Dipt.-chironimid pup.	0	.	0	0	.	0	0	0	.	.	0	0	0	1	.	0	0
Dipt.-chironomid adult	0	0	0	0	0	0	0	0	0	0	.	0	0	.	0	0	0
Dipt.-chironomid larv.	2	0	1	1	1	0	0	0	0	0	0	0	0	3	0	1	0
Dipt.-mayfly nymphs	0	.	0	0	.	0	.	0	0	0	10	.	0	.	0	0	1
Dipt.-mosquito adult	0	0	0	.	.	.	.	0	.	.	.	.	.	.	.	0	0
Dipt.-mosquito larv.	0	0	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Dipt.-mosquito pup.	0	.	0	.	.	.	.	0	.	.	.	.	.	.	.	0	0
Dipt.-phantom midge adult	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Dipt.-phantom midge larv.	2	2	1	1	4	1	1	2	5	6	5	3	2	1	5	2	3
Dipt.-phantom midge pup.	1	1	0	0	.	0	0	0	0	0	0	0	0	.	1	1	0
Diptera	.	0	0	0	.	0	0	0	.	.	0	.	0	0	.	0	0
Gastropoda - snail	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Hemiptera	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Hemiptera - Corixidae	.	.	.	.	.	0	0	.	.	.	.	.	.	.	.	.	0
Hirudinea	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Hydra	1	0	0	1	.	.	0	.	.	.	.	.	.	.	.	1	0
Hymenoptera - ant	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.	0	0
Hymenoptera- diving wasp	0	0	0	0	.	0	.	.	.	.	.	0	.	.	.	0	0
Isopoda	0	0	0	0	.	.	0	0	0	1	0	0	0	0	0	0	0
Megalopt.-alderfly adult	.	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.	0

Table 10. Average Bay and Sound zooplankton density (continued).

PERIOD=N	STATION																
TAXONOMIC GROUP	13	14	15	16	17	18	20	21	22	23	24	26	28	31	32	AVE1	AVE2
Mysidacea - Mysis shrimp	.	.	.	.	.	0	.	0	.	.	.	.	0	.	.	.	0
Nematoda	.	.	0	0	.	.	.	.	.	0	0	.	.	0	.	0	0
Odonata	0	0	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Oligo.- Aeolosoma	0	0	0	0	.	.	0	.	.	.	.	.	.	0	.	0	0
Oligo.- Dero	.	.	0	0	.	.	.	.	.	.	.	.	.	.	.	0	.
Oligo.- Stylaria	1	0	1	0	0	0	1	0	.	.	.	0	0	.	.	1	0
Ostracoda	19	8	5	4	1	2	1	1	1	1	1	1	1	3	1	9	1
Paguridae zoea	.	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.	0
Plecoptera nymph	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Polychaeta	0	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Rotifer - colonial	1	.	1	1	.	1	0	.	.	.	.	.	.	.	.	1	0
Rotifer - single	6	.	2	10	.	1	0	2	0	0	0	0	0	3	0	6	1
Spongillafly adult	0	0	0	0	.	0	.	.	0	.	.	.	0	.	0	0	0
Spongillafly larv.	0	0	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Tadpole	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Thysanoptera (thrip)	.	.	0	0	.	.	.	.	.	.	.	.	.	0	.	0	0
Tubellaria	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Unidentified	1	2	1	1	2	1	0	.	0	0	0	.	0	.	0	1	0
Total density (/m3)	460	495	519	1236	244	396	380	436	1196	971	1169	676	659	297	439	678	624
Avg. vol. sampled (m3)	27	24	28	28	20	30	27	28	30	29	27	28	28	28	29	27	28
(n) Dates sampled	114	46	143	73	9	37	26	31	25	23	24	27	27	32	29	376	290

Table 11. Average density (number/m^3) and relative contribution (%) of taxonomic groups comprising day and night zooplankton communities of the lower Roanoke River (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound, North Carolina, for the period 1984-1991. Period (.) = not observed in samples.

Taxonomic group	Roanoke River Day Ave.	Roanoke River Day %	Roanoke River Night Ave.	Roanoke River Night %	Batchelor Bay Day Ave.	Batchelor Bay Day %	Batchelor Bay Night Ave.	Batchelor Bay Night %	Albemarle Sound Day Ave.	Albemarle Sound Day %	Albemarle Sound Night Ave.	Albemarle Sound Night %
Amphipoda-gammarid egg	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Amphipoda - Gammaridae	.	.	2	0.4	14	3.7	16	3.9	2	0.6	5	1.1
Arachnida	2	0.3	1	0.2	.	.	1	0.2	.	.	1	0.1
Arachnida-tick	.	.	0	0.0	.	.	.	.	.	.	.	.
Bivalvia	.	.	0	0.1	.	.	0	0.1	.	.	0	0.0
Bivalvia-larvae	.	.	0	0.1	.	.	0	0.0	.	.	0	0.0
Caddisfly adult	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Caddisfly larvae	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Clad. - Bosmina	5	2.5	36	9.0	8	2.1	49	12.1	8	2.5	16	3.5
Clad. - Daphnia	79	35.5	67	16.3	358	56.1	58	17.3	7	2.8	19	4.0
Clad. - Leptodora	.	.	0	0.0	.	.	8	1.6	27	11.7	41	7.7
Cladocera - other	101	45.6	125	29.8	84	13.7	68	17.6	4	1.3	27	5.7
Clad.-unid. egg	.	.	0	0.1	1	0.1	1	0.1	.	.	0	0.0
Clad.-unid. juvenile	6	2.1	1	0.3	4	0.7	1	0.3	1	0.1	0	0.1
Coleopt.-Dytiscidae larvae	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Coleopt.-Gyrinidae adult	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Coleopt.-Gyrinidae larvae	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Coleopt.-Peltodytes larvae	.	.	0	0.0	.	.	.	.	.	.	.	.
Coleoptera	.	.	0	0.1	.	.	0	0.0	.	.	.	.
Coleoptera-Elmidae	.	.	0	0.0	.	.	.	.	.	.	.	.
Collembola larvae	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Copepoda-egg mass	.	.	0	0.0	0	0.1	0	0.1	.	.	0	0.0
Copepoda-nauplius	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Copepoda-Argulus	.	.	.	.	.	.	.	.	.	.	0	0.0
Copepoda-Calanoida	6	2.0	24	5.7	50	10.7	49	11.1	149	68.7	46	10.1
Copepoda-Cyclopoida	16	7.0	96	24.3	53	10.4	102	26.3	21	9.8	308	65.8
Copepoda-Harpacticoida	.	.	11	3.0	.	.	13	3.0	1	0.1	1	0.1

Table 11. Day and night zooplankton communities (continued).

Taxonomic group	Roanoke River				Batchelor Bay				Albemarle Sound			
	Day		Night		Day		Night		Day		Night	
	Ave.	%	Ave.	%	Ave.	%	Ave.	%	Ave.	%	Ave.	%
Copepodids	.	.	3	0.7	.	.	2	0.4	3	1.0	0	0.0
Cumacea	.	.	.	.	.	.	.	.	.	.	0	0.0
Decapoda - shrimp larvae	.	.	0	0.0	.	.	.	.	.	.	.	.
Dipt.-biting midge larvae	.	.	0	0.0	.	.	0	0.0	1	0.1	0	0.0
Dipt.-biting midge pupae	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Dipt.-chironomid adults	.	.	0	0.0	.	.	0	0.1	1	0.1	0	0.0
Dipt.-chironomid larvae	.	.	2	0.5	.	.	1	0.3	.	.	0	0.0
Dipt.-chironomid pupae	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Dipt.-mayfly adults	.	.	0	0.0	.	.	.	.	.	.	.	.
Dipt.-mayfly nymphs	.	.	0	0.0	.	.	0	0.0	.	.	1	0.1
Dipt.-mosquito adults	.	.	0	0.0	.	.	0	0.0	1	0.1	0	0.0
Dipt.-mosquito larvae	.	.	0	0.0	.	.	0	0.0	.	.	.	
Dipt.-mosquito pupae	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Dipt.-phantom midge adults	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Dipt.-phantom midge larvae	.	.	2	0.4	.	.	2	0.4	3	0.9	3	0.6
Dipt.-phantom midge pupae	.	.	0	0.1	.	.	1	0.2	.	.	0	0.1
Dipt.-Dixidae adult	.	.	0	0.0	.	.	.	.	.	.	.	.
Diptera	.	.	0	0.0	.	.	0	0.2	1	0.1	0	0.0
Gastropoda-snail	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Gastropoda-egg	.	.	0	0.0	.	.	.	.	.	.	.	.
Hemiptera	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Hemiptera-Belostomatidae	.	.	0	0.0	.	.	.	.	.	.	.	.
Hemiptera-Corixidae	.	.	0	0.0	.	.	.	.	.	.	0	0.0
Hemiptera-Gerridae	.	.	0	0.0	.	.	.	.	.	.	.	.
Hirudinea	.	.	0	0.0	.	.	.	.	.	.	.	.
Hydra	2	0.4	4	0.9	.	.	0	0.0	.	.	0	0.0
Hydra - medusa	.	.	0	0.0	.	.	.	.	.	.	.	.
Hymenoptera-ant	.	.	0	0.0	.	.	0	0.2	.	.	0	0.0

Table 11. Day and night zooplankton communities (continued).

	Roanoke River				Batchelor Bay				Albemarle Sound			
	Day		Night		Day		Night		Day		Night	
Taxonomic group	Ave.	%	Ave.	%	Ave.	%	Ave.	%	Ave.	%	Ave.	%
Hymenoptera-diving wasp	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Isopoda	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Megalopt.-alderfly larvae	.	.	0	0.0	.	.	.	.	.	.	.	.
Megalopt.-alderfly adult	.	.	.	.	.	.	.	.	1	0.1	0	0.0
Mysidacea - Mysis shrimp	.	.	0	0.0	.	.	.	.	.	.	0	0.0
Mysidacea - Mysis zoea	.	.	0	0.0	.	.	.	.	.	.	.	.
Nematoda	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Odonata	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Oligo.-Aeolosoma	1	0.3	1	0.2	0	0.1	0	0.1	.	.	0	0.0
Oligo.-Dero	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Oligo.-Stylaria	.	.	1	0.2	.	.	1	0.2	.	.	0	0.0
Ostracoda	2	0.6	13	3.3	1	0.3	9	2.5	1	0.2	1	0.3
Paguridae zoea	.	.	.	.	.	.	.	.	.	.	0	0.0
Plecoptera adult	.	.	0	0.0	.	.	.	.	.	.	.	.
Plecoptera nymph	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Polychaeta	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Rotifer - colonial	3	0.6	1	0.3	.	.	1	0.1	.	.	0	0.0
Rotifer - single	10	3.2	13	3.1	11	2.0	6	1.1	.	.	1	0.2
Spongillafly adult	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Spongillafly larvae	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Tadpole	.	.	.	.	.	.	0	0.0	.	.	.	.
Tanaid	.	.	0	0.0	.	.	.	.	.	.	.	.
Tardigrada	.	.	0	0.0	.	.	.	.	.	.	.	.
Thysanoptera (thrip)	.	.	0	0.0	.	.	0	0.0	.	.	0	0.0
Tubellaria	.	.	0	0.0	.	.	0	0.0	.	.	.	.
Unidentified	.	.	1	0.0	.	.	1	0.4	.	.	0	0.0
Total ave. density (/m^3)	223	.	481	.	576	.	678	.	209	.	624	.
(n) Total samples	4	4	1309	1309	4	4	376	376	11	11	290	290

Little information is available on differences between the daytime and nighttime zooplankton communities. On occasion several daytime samples were collected for comparative purposes. Even though the average daytime zooplankton abundance appeared similar to those collected at night, the number of taxonomic groups comprising the daytime community was reduced (Table 11). The major taxa, as described above, were still present but the rare organisms disappeared from daytime samples.

Prevailing seasonal river flows appear to have an effect on the species composition of the zooplankton community. In general, cyclopoid copepods represented 20-40% of the total number of individuals in the River (Table 12). Flood conditions in 1987 resulted in a reduction of the cyclopoid copepod population to 7% of total density; cladoceran representation increased to about 86% of all zooplankters, most likely the result of inundation and flushing of adjacent floodplain areas. *Hydra* and rotifers (single and colonial) were in higher abundance than usual. During the 1985 spring drought and subsequent low instream flow, cladoceran representation was small compared to that of copepods. The unusual appearance of the predatory cladoceran *Leptodora* in 1985 river samples was attributed to low flow conditions. Similar trends in abundance with prevailing seasonal flow were evident in Batchelor Bay (Table 13); trends in western Albemarle Sound were not readily apparent because sampling effort was concentrated late in the season (Table 14).

Another method of examining secondary production is by estimating the biomass of the zooplankton community. By estimating the wet weight biomass of each species, the number of individuals becomes less important than the relative size of the organism. In order to calculate biomass the average length and width (mm) of each species must be determined. Geometric formulae are then applied to obtain an estimate of biomass. Mean body lengths and widths were determined for 54 of the 90 taxonomic groupings (Table 15, Table 16). Mean wet weight biomass for each species was then estimated (Table 17) and its relationship to zooplankton body length determined (Table 18). The method produced a conservative estimate of zooplankton wet weight biomass because: 1) rarely encountered zooplankters were not considered, and 2) the biomass estimate did not include appendages.

Zooplankton biomass in the lower Roanoke River is dominated by cladocerans, which contribute 40-86% of the seasonal wet weight estimate (Table 19). Cladoceran biomass contributed more to total biomass in high flow years (1987, 86.2%; 1989, 72.1%; 1990, 61.2%). Copepods represented the second highest biomass, but their percent contribution to zooplankton biomass estimates was lower in high flow years.

In Batchelor Bay, cladocerans and amphipods contribute most of the zooplankton biomass. Gammarid amphipods represented between 14-57% of zooplankton wet weight biomass; no particular seasonal trend with flow was apparent (Table 20). Cladoceran wet weight represented between 20% and 53% among years, while copepods contributed only 5% to 22% of the biomass. Phantom midge larvae and pupae were important biomass contributors, ranging from 1.8% to 11.1% of zooplankton total weight.

Table 12. Relative contribution (% using density) of each taxonomic group to the spring zooplankton community of the lower Roanoke River (Stations 1-12), North Carolina, 1984-1991. Period (.) = not observed in samples.

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Amphipoda-gammarid egg	.	.	.	.	.	.	0.0	0.0
Amphipoda - Gammaridae	0.6	0.1	0.5	0.1	0.3	0.2	1.6	0.7
Arachnida	0.3	0.1	0.0	0.4	0.1	0.3	0.2	0.3
Bivalvia	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Bivalvia-larvae	.	.	.	.	.	0.3	0.0	0.3
Caddisfly adult	.	0.0	.	.	0.0	.	.	.
Caddisfly larvae	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Clad. - *Bosmina*	.	15.1	22.6	6.5	11.3	5.7	2.8	7.8
Clad. - *Daphnia*	.	9.6	14.5	12.3	17.8	28.6	44.8	12.8
Clad. - *Leptodora*	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Cladocera - other	58.4	10.1	15.7	67.6	6.6	24.0	12.0	11.2
Clad.-unid. egg	.	.	.	.	.	0.2	0.1	1.6
Clad.-unid. juvenile	.	.	.	.	.	1.2	0.9	1.2
Coleopt.-Dytiscidae larvae	.	.	.	0.0	.	0.0	0.0	0.0
Coleopt.-Gyrinidae adult	.	0.0	0.0	0.0	.	.	.	.
Coleopt.-Gyrinidae larvae	0.0	0.0	0.0	0.0	.	0.0	0.0	.
Coleopt.-Peltodytes larvae	.	.	.	0.0	.	.	.	.
Coleoptera	0.6	0.0	0.1	.	0.0	0.0	.	0.0
Coleoptera-Elmidae	.	.	.	.	.	0.0	.	0.0
Collembola larvae	.	0.0	.	0.0	0.0	0.0	.	0.0
Copepoda-egg mass	.	.	.	.	.	0.0	0.1	0.5
Copepoda-nauplius	.	.	0.0	.	0.0	0.0	0.0	0.1
Copepoda-Calanoida	4.5	6.2	10.7	0.4	15.2	2.2	5.6	6.8
Copepoda-Cyclopoida	20.3	38.6	30.3	7.1	40.4	15.5	24.0	28.4
Copepoda-Harpacticoida	4.9	12.9	0.2	0.1	0.0	0.1	0.0	0.0
Copepodids	.	0.1	0.8	.	0.8	3.1	0.3	0.2
Decapoda - shrimp larvae	.	.	0.0	.	.	.	.	.
Dipt.-biting midge larvae	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Dipt.-biting midge pupae	.	.	.	0.0	0.0	.	0.0	0.0
Dipt.-chironomid adult	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Dipt.-chironomid larvae	1.2	0.3	0.5	0.0	0.3	0.5	0.4	0.6
Dipt.-chironomid pupae	.	.	.	0.0	.	0.1	0.0	0.0
Dipt.-mosquito adult	0.0	0.0	0.0	0.0	0.0	.	.	.
Dipt.-mosquito larvae	0.0	0.7	0.0	0.0	.	0.0	0.0	0.0
Dipt.-mosquito pupae	0.0	0.1	0.0	0.0	.	.	.	.
Dipt.-phantom midge adult	.	.	.	0.0	.	.	.	.
Dipt.-phantom midge larvae	0.4	0.0	0.3	0.1	0.4	0.3	0.4	0.9
Dipt.-phantom midge pupae	0.2	0.0	0.1	0.1	0.1	0.0	0.0	0.1
Dipt.-Dixidae adult	.	.	.	0.0	.	0.0	.	.
Diptera	.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eph.-mayfly adults	.	.	.	.	0.0	.	.	.
Eph.-mayfly nymphs	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 12. Lower Roanoke River zooplankton contribution (% by density, continued).

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Gastropoda-snail	0.0	0.0	0.0	0.0	.	0.0	.	.
Gastropoda-egg	.	.	.	.	.	0.0	.	.
Hemiptera	0.0	0.0	0.0	0.0	0.0	.	.	0.0
Hemiptera-Belostomatidae	.	.	0.0	.	.	.	.	.
Hemiptera-Corixidae	.	.	.	.	.	.	0.0	0.0
Hemiptera-Gerridae	.	.	.	.	.	0.0	.	.
Hirudinea	.	.	.	0.0	0.0	.	.	.
Hydra	0.5	0.0	0.1	1.9	1.2	1.8	0.4	0.8
Hydra - medusa	.	0.0	.	.	0.0	.	.	.
Hymenoptera-ant	.	.	.	.	.	0.0	.	0.0
Hymenoptera-diving wasp	0.0	0.0	0.0	0.0	.	0.0	.	0.0
Isopoda	.	0.0	.	.	0.0	0.0	0.0	.
Megalopt.-alderfly larvae	.	.	0.0	.	.	.	.	0.0
Mysidacea - Mysis shrimp	0.0	.	.	.	.	.	.	.
Mysidacea - Mysis zoea	0.0	.	.	.	.	.	.	.
Nematoda	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Odonata	0.0	0.0	.	.	0.0	0.0	0.0	0.0
Oligo.-*Aeolosoma*	0.1	0.1	0.3	0.0	0.3	0.5	0.2	0.4
Oligo.-*Dero*	0.0	.	.	0.0	0.0	0.0	0.0	0.1
Oligo.-*Stylaria*	0.3	0.1	.	0.3	0.1	0.4	0.3	0.3
Ostracoda	5.4	5.3	2.5	0.8	1.6	3.6	2.9	4.6
Plecoptera adult	.	0.0	.	0.0	.	.	.	.
Plecoptera nymph	.	.	.	0.0	0.0	.	.	.
Polychaeta	0.1	.	0.0	.	0.0	.	.	.
Rotifer - colonial	.	.	.	1.2	.	0.4	0.1	1.1
Rotifer - single	.	.	.	0.4	3.0	10.7	2.3	18.5
Spongillafly adult	0.0	0.0	.	0.0	0.0	.	.	.
Spongillafly larvae	0.0	0.0	.	0.0	0.0	0.0	.	.
Tanaid	.	.	.	.	.	0.0	.	.
Tardigrada	.	.	.	.	.	0.0	.	0.0
Thysanoptera (thrip)	.	.	.	.	.	0.0	0.0	0.1
Tubellaria	.	.	.	.	.	.	.	0.0
Unidentified	1.4	0.4	0.2	0.0	0.0	0.1	0.1	0.1
Total average density (/m^3)	559	426	324	606	309	386	342	196
(n) Total samples	131	178	179	163	171	198	149	140

Table 13. Relative contribution (% using density) of each taxonomic group to the spring zooplankton community of Batchelor Bay (Stations 13-16), North Carolina, 1984-1991. Period (.) = not observed in samples.

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Amphipoda-gammarid egg	.	.	.	.	.	0.0	0.1	0.0
Amphipoda - Gammaridae	5.1	1.1	2.2	5.9	7.1	10.0	4.8	2.7
Arachnida	0.3	0.0	.	0.4	0.1	0.3	0.1	0.3
Bivalvia	0.3	0.0	0.0	0.1	0.0	0.0	.	.
Bivalvia-larvae	.	.	.	.	.	0.0	0.2	0.1
Caddisfly adult	0.0	0.0	.	.	0.0	.	.	.
Caddisfly larvae	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1
Clad. - *Bosmina*	.	17.6	20.0	13.2	16.6	7.0	3.5	16.9
Clad. - *Daphnia*	.	23.9	7.5	17.5	17.9	25.8	37.6	11.2
Clad. - *Leptodora*	2.3	4.0	0.8	0.1	0.1	0.2	0.0	0.2
Cladocera - other	46.9	4.5	8.9	41.1	2.6	19.9	10.4	9.9
Clad.-unid. egg	.	.	.	.	.	0.6	0.1	1.0
Clad.-unid. juvenile	.	.	.	.	.	1.7	0.8	1.0
Coleopt.-Dytiscidae larvae	.	.	.	0.0	.	0.0	0.0	.
Coleopt.-Gyrinidae adult	.	0.0	.	.	.	.	.	.
Coleopt.-Gyrinidae larvae	.	0.0	0.0	0.0	.	0.0	0.0	.
Coleopt.-Peltodytes larvae	.	.	.	.	.	.	.	.
Coleoptera	0.0	.	0.0	.	.	.	.	0.0
Coleoptera-Elmidae	.	.	.	.	.	.	.	.
Collembola larvae	.	.	.	.	.	.	0.0	.
Copepoda-egg mass	.	.	.	.	.	0.0	0.2	0.7
Copepoda-nauplius	.	.	.	.	.	.	0.0	0.0
Copepoda-*Argulus* sp.	.	.	.	.	.	.	.	.
Copepoda-Calanoida	5.4	7.0	36.1	0.8	12.6	1.7	10.0	9.9
Copepoda-Cyclopoida	22.6	32.4	20.8	15.4	35.5	22.7	27.8	31.6
Copepoda-Harpacticoida	5.9	6.9	0.1	0.8	0.0	.	.	0.0
Copepodids	.	0.1	0.6	.	0.4	3.4	0.3	0.2
Cumacea	.	.	.	.	.	.	..	
Decapoda - shrimp larvae	.	.	.	.	.	.	..	
Dipt.-biting midge larvae	0.1	0.0	0.0	0.1	.	0.0	0.0	0.0
Dipt.-biting midge pupae	.	.	.	.	.	.	.	.
Dipt.-chironomid adult	0.2	0.0	0.0	.	0.0	0.1	0.1	0.0
Dipt.-chironomid larvae	0.6	0.1	0.1	0.4	0.2	0.1	0.4	0.7
Dipt.-chironomid pupae	.	.	.	.	.	0.0	0.0	0.0
Dipt.-mosquito adult	.	0.0	0.0	.	.	.	.	.
Dipt.-mosquito larvae	0.0	.	.	0.0	.	.	.	.
Dipt.-mosquito pupae	0.1	.	0.0	.	.	.	.	.
Dipt.-phantom midge adult	.	.	.	0.0	.	.	.	.
Dipt.-phantom midge larvae	0.7	0.4	0.3	0.1	0.4	0.4	0.3	0.6
Dipt.-phantom midge pupae	0.5	0.1	0.2	0.1	0.1	0.1	0.1	0.0
Dipt.-Dixidae adult	.	.	.	.	.	.	.	.
Diptera	.	0.0	0.0	0.0	0.0	.	.	0.0
Eph.-mayfly adults	.	.	.	.	.	.	.	.
Eph.-mayfly nymphs	0.0	0.0	0.0	.	0.0	0.0	0.0	0.0

Table 13. Batchelor Bay zooplankton contribution (% by density, continued).

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Gastropoda-snail	0.0	.	.	.	.	.	.	.
Gastropoda-egg	.	.	.	.	.	.	.	.
Hemiptera	0.1	.	.	.	.	.	.	.
Hemiptera-Belostomatid	.	.	.	.	.	.	.	.
Hemiptera-Corixidae	.	.	.	.	.	.	0.0	.
Hemiptera-Gerridae	.	.	.	.	.	.	.	.
Hirudinea	.	.	.	.	.	0.0	.	.
Hydra	.	.	0.1	1.0	.	0.8	0.0	.
Hydra - medusa	.	.	.	.	.	.	.	.
Hymenoptera-ant	.	.	.	.	0.0	.	.	.
Hymenoptera-diving wasp	0.0	0.0	0.0	0.1	.	0.0	.	.
Isopoda	.	0.0	.	.	0.1	0.0	0.0	0.0
Megalopt.-alderfly larvae	.	.	.	.	.	.	.	.
Mysidacea - Mysis shrimp	.	.	.	.	.	.	.	.
Mysidacea - Mysis zoea	.	.	.	.	.	.	.	.
Nematoda	0.0	.	.	.	.	0.0	.	0.0
Odonata	0.0	0.0	0.0	.	.	.	0.0	0.0
Oligo.-*Aeolosoma*	0.0	0.0	0.1	0.0	.	0.1	0.0	0.2
Oligo.-*Dero*	0.0	.	.	0.0	.	.	.	.
Oligo.-*Stylaria*	0.4	0.0	.	0.3	0.0	0.6	0.5	0.3
Ostracoda	6.6	1.5	2.0	1.7	1.8	1.3	1.5	.
Paguridae zoea	.	.	.	.	.	.	.	.
Plecoptera adult	.	.	.	.	.	.	.	.
Plecoptera nymph	.	.	.	0.0	.	.	.	.
Polychaeta	0.0	.	.	.	.	.	.	.
Rotifer - colonial	.	.	.	0.6	.	0.0	0.0	1.1
Rotifer - single	.	.	.	0.2	4.3	2.8	0.7	7.9
Spongillafly adult	0.0	0.0	.	0.0	0.0	.	.	0.0
Spongillafly larvae	0.0	0.0	.	.	.	.	.	.
Tadpole	.	.	.	0.0	.	.	.	.
Tanaid	.	.	.	.	.	.	.	.
Tardigrada	.	.	.	.	.	.	.	.
Thysanoptera (thrip)	.	.	.	.	.	.	0.0	0.0
Tubellaria	.	.	.	.	.	.	.	0.0
Unidentified	1.5	0.2	0.1	0.0	0.0	0.1	0.1	0.1
Total average density (/m^3)	605	563	479	265	207	231	377	208
(n) Total samples	44	54	45	47	41	48	45	52

Table 14. Relative contribution (% using density) of each taxonomic group to the spring zooplankton community of Western Albemarle Sound (Stations 17-32), North Carolina, 1984-1991. Period (.) = not observed in samples.

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Amphipoda-gammarid egg	.		.	.	.	.	0.0	.
Amphipoda - Gammaridae	3.0		0.4	1.3	1.7	1.4	1.3	0.3
Arachnida	0.6		.	0.1	0.0	0.0	0.2	0.1
Bivalvia	.		.	0.0	.	0.0	0.0	0.0
Bivalvia-larvae	.		.	.	.	.	.	0.0
Caddisfly adult	.		.	.	.	.	.	.
Caddisfly larvae	.		.	.	0.0	0.0	0.0	.
Clad. - *Bosmina*	.		0.2	4.7	0.9	11.4	1.3	2.5
Clad. - *Daphnia*	.		0.8	6.4	1.2	8.1	4.8	1.0
Clad. - *Leptodora*	36.4		0.7	9.8	9.3	7.1	10.3	2.7
Cladocera - other	28.5		0.0	2.1	0.3	7.0	9.1	7.1
Clad.-unid. egg	.		.	.	.	0.1	0.0	0.0
Clad.-unid. juvenile	.		.	.	.	0.2	0.0	0.1
Coleopt.-Dytiscidae larvae	.		.	.	.	.	0.0	.
Coleopt.-Gyrinidae adult	.		.	.	.	.	.	.
Coleopt.-Gyrinidae larvae	.		.	0.0	.	.	.	.
Coleopt.-Peltodytes larvae	.		.	.	.	.	.	.
Coleoptera	.		.	.	.	.	.	.
Coleoptera-Elmidae	.		.	.	.	.	.	.
Collembola larvae	.		.	.	.	.	.	.
Copepoda-egg mass	.		.	.	.	0.1	0.0	0.1
Copepoda-nauplius	.		0.0	.	.	.	.	.
Copepoda-*Argulus* sp.	.		.	.	.	.	.	0.0
Copepoda-Calanoida	6.3		89.3	2.6	10.7	3.4	2.4	2.2
Copepoda-Cyclopoida	14.8		7.2	71.7	74.4	59.9	68.3	82.2
Copepoda-Harpacticoida	3.4		0.0	0.3	.	.	.	0.0
Copepodids	.		0.1	.	0.2	.	0.0	0.0
Cumacea	.		.	.	.	.	0.0	.
Decapoda - shrimp larvae	.		.	.	.	.	.	.
Dipt.-biting midge larvae	0.1		0.0	0.0	.	0.0	.	0.0
Dipt.-biting midge pupae	.		.	.	.	.	.	.
Dipt.-chironomid adult	0.2		0.0	.	0.0	.	0.0	0.0
Dipt.-chironomid larvae	0.1		.	0.0	0.0	0.0	0.3	0.0
Dipt.-chironomid pupae	.		.	.	0.0	0.0	0.1	0.0
Dipt.-mosquito adult	.		0.0	.	.	.	.	.
Dipt.-mosquito larvae	.		.	.	.	.	.	.
Dipt.-mosquito pupae	.		.	0.0	.	.	.	.
Dipt.-phantom midge adult	.		.	.	.	.	.	.
Dipt.-phantom midge larvae	1.9		1.0	0.6	0.5	0.4	0.5	0.7
Dipt.-phantom midge pupae	0.5		0.0	0.1	0.0	.	0.0	0.1
Dipt.-Dixidae adult	.		.	.	.	.	.	.
Diptera	.		.	0.0	.	0.0	0.0	0.0
Eph.-mayfly adults	.		.	.	.	.	.	.
Eph.-mayfly nymphs	.		.	.	0.0	0.0	0.7	0.0

Table 14. Western Albemarle Sound zooplankton contribution (% by density, continued).

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Gastropoda-snail	.		.	.	.	.	.	.
Gastropoda-egg	.		.	.	.	.	.	.
Hemiptera	.		.	.	.	.	0.0	.
Hemiptera-Belostomatid	.		.	.	.	.	.	.
Hemiptera-Corixidae	.		.	.	.	.	0.0	.
Hemiptera-Gerridae	.		.	.	.	.	.	.
Hirudinea	.		.	.	.	.	.	.
Hydra	.		0.0	0.0	.	.	0.0	.
Hydra - medusa	.		.	.	.	.	.	.
Hymenoptera-ant	.		.	.	.	.	.	0.0
Hymenoptera-diving wasp	.		.	0.0	.	.	.	0.0
Isopoda	.		.	.	.	0.1	0.1	0.0
Megalopt.-alderfly larvae	.		0.0	.	.	.	.	.
Mysidacea - Mysis shrimp	.		.	.	.	.	.	0.0
Mysidacea - Mysis zoea	.		.	.	.	.	.	.
Nematoda	.		.	.	.	.	0.0	0.0
Odonata	.		.	.	.	.	.	.
Oligo.-*Aeolosoma*	.		.	.	.	.	0.0	.
Oligo.-*Dero*	.		.	.	.	.	.	.
Oligo.-*Stylaria*	.		.	0.0	.	0.1	0.0	0.0
Ostracoda	2.1		0.1	0.3	0.7	0.2	0.2	0.1
Paguridae zoea	.		0.0	.	.	.	.	.
Plecoptera adult	.		.	.	.	.	.	.
Plecoptera nymph	.		.	.	.	.	.	.
Polychaeta	.		.	.	.	.	.	.
Rotifer - colonial	.		.	.	.	.	0.0	0.1
Rotifer - single	.		.	.	0.0	0.6	0.0	0.4
Spongillafly adult	.		.	0.0	.	.	.	.
Spongillafly larvae	.		.	.	.	.	.	.
Tadpole	.		.	.	.	.	.	.
Tanaid	.		.	.	.	.	.	.
Tardigrada	.		.	.	.	.	.	.
Thysanoptera (thrip)	.		.	.	.	.	.	0.0
Tubellaria	.		.	.	.	.	.	.
Unidentified	1.8		0.1	0.0	.	0.0	0.0	0.0
Total average density (/m3)	386	.	518	510	308	593	555	482
(n) Total samples	6	0	20	65	43	31	62	63

Table 15. Mean (± standard deviation) and range of lengths (mm) and widths (mm) of selected zooplankton taxonomic groups from the lower Roanoke River, delta, and western Albemarle Sound, 1984-1991.

		Length (mm)				Width (mm)			
Taxonomic group	n	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Bosmina	21	0.419	0.062	0.320	0.600	0.424	0.071	0.320	0.640
Daphnia	34	1.206	0.244	0.680	1.760	0.628	0.166	0.400	1.080
Sididae	12	1.377	0.210	0.960	1.800	0.637	0.144	0.480	0.880
Chydorinae	27	0.892	0.232	0.680	1.760	0.524	0.201	0.360	1.280
Leptodora kindti	24	3.487	0.907	2.280	5.000	0.337	0.082	0.200	0.520
Cladoceran juveniles	27	0.252	0.052	0.120	0.400	0.132	0.037	0.080	0.200
Cyclopoid copepods	16	1.498	0.107	1.280	1.600	0.498	0.057	0.360	0.600
Calanoid copepods	16	1.175	0.105	0.920	1.320	0.315	0.040	0.240	0.360
Copepodites	12	0.580	0.139	0.320	0.800	0.227	0.126	0.160	0.640
Copepod nauplii	10	0.172	0.065	0.080	0.280	0.100	0.027	0.080	0.160
Copepod eggs	32	0.085	0.010	0.080	0.120	0.078	0.007	0.060	0.080
Ostracods	16	0.568	0.032	0.520	0.600	0.289	0.048	0.200	0.400
Chironomid larvae	8	4.285	0.627	3.400	5.400	0.535	0.049	0.440	0.600
Chironomid pupae	18	4.529	0.968	3.000	6.640	0.753	0.223	0.320	1.200
Phantom midge larvae	8	7.480	0.844	6.040	8.520	0.635	0.095	0.520	0.800
Phantom midge pupae	19	6.183	0.714	4.800	7.200	0.840	0.091	0.600	0.960
Biting midge larvae	6	6.653	0.981	4.680	7.480	0.293	0.055	0.200	0.360
Aeolosoma	6	0.907	0.085	0.800	1.040	0.143	0.018	0.120	0.160
Dero	13	2.452	0.622	1.360	3.680	0.305	0.039	0.240	0.360
Stylaria	13	3.397	0.731	2.080	4.800	0.297	0.069	0.220	0.480
Rotifers	33	0.105	0.020	0.080	0.160	0.082	0.012	0.060	0.120
Nematodes	2	3.200	0.800	2.400	4.000	0.080	0.000	0.080	0.080
Caddisfly larvae	1	3.520	.	.	.	0.400	.	.	.
Bivalve	9	1.587	0.454	0.800	2.200	0.787	0.172	0.480	1.000
Bivalve larvae	1	0.280	.	.	.	0.200	.	.	.
Gammarids	9	3.431	1.229	1.760	6.480	0.729	0.254	0.400	1.360
Gammarid eggs	1	0.600	.	.	.	0.520	.	.	.
Gastropods	1	1.240	.	.	.	0.600	.	.	.
Collembola	1	1.480	.	.	.	0.320	.	.	.
Chironomid adults	3	4.507	1.971	2.880	7.280	0.880	0.510	0.480	1.600
Peltodytes larvae	1	4.520	.	.	.	0.800	.	.	.
Colonial rotifers	3	0.667	0.124	0.560	0.840	0.667	0.124	0.560	0.840
Hydra	7	1.823	0.653	1.400	3.360	0.366	0.112	0.200	0.520
Caddisfly adults	3	6.587	1.433	5.200	8.560	1.547	0.593	0.880	2.320
Arachnids	6	0.980	0.158	0.760	1.200	0.673	0.154	0.520	1.000
Megaloptera larvae	1	9.600	.	.	.	1.600	.	.	.
Freshwater polychaete	1	2.560	.	.	.	0.240	.	.	.
Turbellarians	3	2.387	0.774	1.520	3.400	0.733	0.151	0.520	0.840
Snail eggs	1	0.600	.	.	.	0.600	.	.	.
Dixidae adults	2	5.400	0.200	5.200	5.600	1.040	0.240	0.800	1.280
Gerridae adults	3	1.480	0.065	1.400	1.560	0.547	0.050	0.480	0.600
Corixidae	6	3.307	0.420	2.400	3.680	1.493	0.171	1.120	1.600

Table 15. Zooplankton mean lengths and widths (continued).

Taxonomic group	n	Length (mm)				Width (mm)			
		Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Cladoceran eggs	9	0.224	0.013	0.200	0.240	0.151	0.021	0.120	0.180
Hirudinea	3	7.627	1.255	6.240	9.280	1.280	0.558	0.640	2.000
Spongillafly larvae	3	3.560	0.170	3.440	3.800	1.467	0.094	1.400	1.600
Harpacticoid copepods	2	0.460	0.060	0.400	0.520	0.140	0.020	0.120	0.160
Isopods	1	5.200	.	.	.	2.400	.	.	.
Dytiscidae larvae	5	5.152	0.625	4.160	6.000	1.088	0.241	0.640	1.360
Gyrinidae larvae	2	7.880	0.920	6.960	8.800	0.880	0.240	0.640	1.120
Limpet	1	4.400	.	.	.	2.880	.	.	.
Argulus sp.	1	2.200	.	.	.	1.400	.	.	.
Mayfly adults	3	13.090	7.500	2.800	20.480	1.893	0.915	0.800	3.040
Elmidae	3	5.493	0.264	5.200	5.840	0.667	0.100	0.560	0.800
Mysid shrimp	5	1.496	0.199	1.320	1.880	0.216	0.041	0.160	0.280

Table 16. Length (L, mm)-width (W, mm) relationships of zooplankton prey collected from the lower Roanoke River, delta, and western Albemarle Sound, in 1991. df=degrees of freedom; r^2=coefficient of determination.

Taxonomic group	df	Regression	r^2
Bosmina	19	W = 0.9765L + 0.0146	0.74
Daphnia	32	W = 0.5690L - 0.0579	0.70
Sididae	10	W = 0.5150L - 0.0723	0.57
Chydorinae	25	W = 0.8382L - 0.2231	0.94
Leptodora kindti	22	W = 0.0842L + 0.0431	0.88
Cladoceran juveniles	25	W = 0.5069L + 0.0042	0.51
Cyclopoid copepods	14	W = 0.4120L - 0.1194	0.61
Calanoid copepods	14	W = 0.2711L - 0.0035	0.51
Copepodites	10	W = 0.5034L - 0.0653	0.31
Copepod nauplii	8	W = 0.3195L + 0.0450	0.60
Copepod eggs	30	W = 0.1250L + 0.0669	0.04
Ostracods	14	W = 0.1855L + 0.1835	0.01
Chironomid larvae	6	W = 0.0517L + 0.3134	0.44
Chironomid pupae	16	W = 0.2004L - 0.1542	0.76
Phantom midge larvae	6	W = 0.0871L - 0.0163	0.60
Phantom midge pupae	17	W = 0.0930L + 0.2647	0.53
Biting midge larvae	4	W = 0.0436L + 0.0031	0.61
Aeolosoma	4	W = 0.0610L + 0.0880	0.08
Dero	11	W = 0.0479L + 0.1871	0.57
Stylaria	11	W = 0.0634L + 0.0815	0.45
Rotifers	31	W = 0.3966L + 0.0406	0.44
Isopods	2	W = 0.0246L + 0.2139	0.09
Bivalve	7	W = 0.3664L + 0.2053	0.94
Gammarids	7	W = 0.2050L + 0.0256	0.98
Chironomid adults	1	W = 0.2554L - 0.2710	0.97
Hydra	5	W = 0.0875L + 0.2062	0.26
Caddisfly adults	1	W = 0.4079L - 1.1400	0.97
Arachnids	4	W = 0.7540L - 0.0656	0.60
Turbellarians	1	W = 0.1541L + 0.3655	0.63
Gerridae adults	1	W = 0.5000L - 0.1933	0.43
Corixidae	4	W = 0.4032L + 0.1600	0.98
Cladoceran eggs	7	W = 1.0938L - 0.0944	0.42
Hirudinea	1	W = -0.2410L + 3.1178	0.29
Spongillafly larvae	1	W = 0.2778L + 2.4556	0.25
Dytiscidae larvae	3	W = -0.3218L + 2.7457	0.70
Mayfly adults	1	W = 0.1158L + 0.3769	0.90
Elmidae	1	W = -0.3571L + 2.6286	0.89
Mysid shrimp	3	W = 0.1883L - 0.0657	0.84

Table 17. Mean (± standard deviation) and range of wet weight biomass (g), and dry weight biomass (µg) of selected zooplankton taxonomic groups from the lower Roanoke River, delta, and western Albemarle Sound, 1984-1991. Biomass estimates are conservative, calculated using geometric formulae and assuming a density of pure water (1 cc = 1 g).

	Wet weight biomass per animal (g)					Dry biomass	
Taxonomic group	n	Mean	S.D.	Min	Max	n	µg/animal
Bosmina	21	0.031832	0.018580	0.012868	0.096510	104	1.8
Daphnia	34	0.218194	0.163329	0.060319	0.691150	170	5.0
Sididae	12	0.242376	0.142435	0.086859	0.547391	60	12.6
Chydorinae	27	0.138387	0.223054	0.034608	1.132381	133	7.7
Leptodora kindti	24	0.366425	0.258025	0.075398	1.044869	106	4.1
Cladoceran juveniles	27	0.002002	0.001424	0.000302	0.006283	27	0.7
Cyclopoid copepods	16	0.099455	0.026374	0.044787	0.150796	87	17.8
Calanoid copepods	16	0.031480	0.009529	0.013873	0.044787	84	7.7
Copepodites	12	0.012135	0.022278	0.002145	0.085786	59	3.7
Copepod nauplii	10	0.000839	0.000712	0.000201	0.002413	48	5.2
Copepod eggs	32	0.000203	0.000042	0.000113	0.000302	201	0.4
Ostracods	16	0.017703	0.005426	0.008168	0.026465	85	35.5
Chironomid larvae	8	0.988320	0.293069	0.583884	1.526814	30	68.3
Chironomid pupae	1	2.425072	1.796529	0.241274	7.509663	18	271.0
Phantom midge larvae	8	2.483837	0.963499	1.282725	4.222301	22	154.0
Phantom midge pupae	19	3.525589	0.980782	1.357168	5.066761	19	337.0
Biting midge larvae	6	0.483051	0.199715	0.147027	0.745085	6	63.3
Aeolosoma	6	0.014962	0.004313	0.009500	0.020910	6	1.6
Dero	13	0.190661	0.090425	0.072206	0.374578	13	30.7
Stylaria	13	0.266230	0.197221	0.092752	0.868588	31	4.8
Rotifers	33	0.000199	0.000102	0.000075	0.000528	800	0.9
Nematodes	2	0.016085	0.004021	0.012064	0.020106	.	.
Caddisfly larvae	1	0.442336	.	.	.	.	.
Bivalve	9	0.707487	0.454584	0.090478	1.451416	.	.
Bivalve larvae	1	0.006158	.	.	.	.	.
Gammarids	9	2.044576	2.650232	0.221168	9.413317	.	.
Gammarid eggs	1	0.063711	.	.	.	.	.
Gastropods	1	0.280481	.	.	.	.	.
Collembola	1	0.119029	.	.	.	.	.
Chironomid adults	3	5.318222	6.589719	0.608011	14.637308	.	.
Peltodytes larvae	1	2.272000	.	.	.	.	.
Mosquito larvae	1	0.063938	.	.	.	.	.
Colonial rotifers	3	0.171796	0.098344	0.091952	0.310339	.	.
Hydra	7	0.234194	0.213890	0.059062	0.713569	.	.
Caddisfly adults	3	16.373411	14.267002	3.162704	36.185920	.	.
Arachnids	6	0.389382	0.257366	0.161402	0.942478	.	.
Megaloptera larvae	1	19.301945	.	.	.	.	.
Freshwater polychaetes	1	0.115812	.	.	.	.	.
Turbellarians	3	0.214391	0.141930	0.062078	0.403757	.	.
Snail eggs	1	0.113097	.	.	.	.	.
Dixidae adults	2	4.909932	2.296127	2.613805	7.206060	.	.

Table 17. Zooplankton wet weight biomass (continued).

Taxonomic group	Wet weight biomass per animal (g) n	Mean	S.D.	Min	Max	Dry biomass n	µg/animal
Gerridae adults	3	0.352009	0.071157	0.253338	0.418460	.	.
Corixidae	6	2.301087	0.684197	1.013352	3.007886	.	.
Cladoceran eggs	9	0.002074	0.000657	0.001244	0.003054	.	.
Hirudinea	3	3.539896	3.382926	1.119513	8.323964	.	.
Spongillafly larvae	3	1.6955455	0.159745	1.512991	1.902046	.	.
Harpacticoid copepods	2	0.007490	0.002966	0.004524	0.010455	.	.
Isopods	1	10.585911	.	.	.	.	.
Dytiscidae larvae	5	1.752777	0.624141	0.603186	2.424807	.	.
Gyrinidae larvae	2	5.454408	3.215382	2.239026	8.669790	.	.
Limpet	1	9.156360	.	.	.	.	.
Argulus sp.	1	0.725708	.	.	.	.	.
Mayfly adults	3	64.200951	62.031662	1.407434	148.650714	.	.
Elmidae	3	1.934082	0.497191	1.438397	2.613805	.	.
Mysid shrimp	5	0.059444	0.030948	0.026540	0.115761	.	.

Table 18. Length (L, mm)-biomass (B, g) relationships of zooplankton prey collected from the lower Roanoke River, delta, and western Albemarle Sound, in 1991. df=degrees of freedom; r^2=coefficient of determination. Biomass calculated by geometric formulae and assuming a density of pure water (1 cc=1 g). E=ellipse; C=cylinder; CN=cone; S=sphere.

Taxonomic group	df	Shape	Regression	r^2
Bosmina	19	E	B = 0.2683L - 0.0806	0.81
Daphnia	32	E	B = 0.5785L - 0.4794	0.75
Sididae	10	E	B = 0.5676L - 0.5391	0.70
Chydorinae	25	E	B = 0.9165L - 0.6790	0.91
Leptodora kindti	22	C	B = 0.2678L - 0.5673	0.89
Cladoceran juveniles	25	E	B = 0.0224L - 0.0036	0.67
Cyclopoid copepods	14	CN	B = 0.2117L - 0.2176	0.73
Calanoid copepods	14	CN	B = 0.0744L - 0.0559	0.67
Copepodites	10	CN	B = 0.0869L - 0.0383	0.29
Copepod nauplii	8	E	B = 0.0093L - 0.0008	0.72
Copepod eggs	30	E	B = 0.0031L - 0.0001	0.53
Ostracods	14	C	B = 0.0565L - 0.0129	0.07
Chironomid larvae	6	C	B = 0.4295L - 0.8522	0.84
Chironomid pupae	16	C	B = 1.7504L - 5.5025	0.89
Phantom midge larvae	6	C	B = 0.9450L - 4.5849	0.68
Phantom midge pupae	17	C	B = 1.2070L - 3.9378	0.77
Biting midge larvae	4	C	B = 0.1708L - 0.6535	0.70
Aeolosoma	4	C	B = 0.0303L - 0.0125	0.36
Dero	11	C	B = 0.1356L - 0.1418	0.87
Stylaria	11	C	B = 0.2099L - 0.4466	0.61
Rotifers	31	CN	B = 0.0042L - 0.0002	0.67
Isopods	2	C	B = 0.0827L - 0.0540	0.46
Bivalve	7	E	B = 0.9727L - 0.8358	0.94
Gammarids	7	C	B = 2.0435L - 4.9671	0.90
Chironomid adults	1	C	B = 3.3249L - 9.6662	0.99
Colonial rotifers	1	S	B = 0.7946L - 0.3579	1.00
Hydra	5	C	B = 0.2939L - 0.3015	0.81
Caddisfly adults	1	C	B = 0.9477L - 49.1489	1.00
Arachnids	4	C	B = 1.3000L - 0.8846	0.64
Turbellarians	1	E	B = 0.1830L - 0.2224	1.00
Gerridae adults	1	C	B = 0.8181L - 0.8587	0.56
Corixidae	4	E	B = 1.5277L - 2.7505	0.88
Cladoceran eggs	7	E	B = 0.0398L - 0.0069	0.58
Hirudinea	1	E	B = -0.4230L + 6.7661	0.02
Spongillafly larvae	1	E	B = -0.1005L + 2.0533	0.01
Dytiscidae larvae	3	E	B = -0.5853L + 4.7680	0.34
Mayfly adults	1	C	B = 7.1448L - 29.3478	0.75
Elmidae	1	C	B = -1.7287L + 11.4302	0.84
Mysid shrimp	3	C	B = 0.1535L - 0.1702	0.97

Table 19. Relative contribution (% using biomass) of each taxonomic group to the spring zooplankton community of the lower Roanoke River (Stations 1-12), North Carolina, 1984-1991. Period (.) = not observed in samples, or no weight estimate available.

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Amphipoda-gammarid egg	.	.	.	.	.	.	.	.
Amphipoda - Gammaridae	5.2	1.2	7.0	1.2	4.2	2.5	15.6	10.3
Arachnida	0.5	0.3	0.1	0.7	0.2	0.6	0.4	0.8
Bivalvia	0.5	0.2	0.2	0.1	0.7	0.2	0.1	0.1
Bivalvia-larvae	.	.	.	.	.	0.0	0.0	0.0
Caddisfly adult	.	0.1	.	.	0.4	0.1	.	.
Caddisfly larvae	0.1	0.1	0.1	0.0	0.2	0.1	0.2	0.3
Clad. - *Bosmina*	.	3.9	5.0	0.9	2.7	1.1	0.4	1.7
Clad. - *Daphnia*	.	16.9	22.1	12.0	29.6	36.7	46.8	19.2
Clad. - *Leptodora*	0.0	0.4	0.1	0.0	0.0	0.0	0.1	0.0
Cladocera - other	65.0	19.7	26.6	73.3	12.2	34.3	13.9	18.7
Clad.-unid. egg	.	.	.	.	.	0.0	0.0	0.0
Clad.-unid. juvenile	.	.	.	.	.	0.0	0.0	0.0
Coleopt.-Dytiscidae larvae	.	.	.	0.1	.	0.1	0.0	0.0
Coleopt.-Gyrinidae adult	.	.	.	.	.	.	.	.
Coleopt.-Gyrinidae larvae	1.0	0.1	1.2	0.3	.	0.3	0.1	.
Coleopt.-Peltodytes larvae	.	.	.	0.0	.	.	.	.
Coleoptera	.	.	.	.	.	.	.	.
Coleoptera-Elmidae	.	.	.	.	.	0.0	.	0.1
Collembola larvae	.	0.0	.	0.0	0.0	0.0	.	0.0
Copepoda-egg mass	.	.	.	.	.	0.0	0.0	0.0
Copepoda-nauplius	.	.	0.0	.	0.0	0.0	0.0	0.0
Copepoda-Calanoida	0.7	1.6	2.4	0.1	3.6	0.4	0.8	1.5
Copepoda-Cyclopoida	9.3	31.0	21.1	3.2	30.5	9.0	11.4	19.4
Copepoda-Harpacticoida	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Copepodids	.	0.0	0.1	.	0.1	0.2	0.0	0.0
Decapoda - shrimp larvae	.	.	.	.	.	.	.	.
Dipt.-biting midge larvae	0.1	0.0	0.2	0.1	0.0	0.1	0.1	0.0
Dipt.-biting midge pupae	.	.	.	0.0	.	.	.	0.6
Dipt.-chironomid adult	1.6	2.2	0.4	0.2	0.6	0.7	0.4	0.8
Dipt.-chironomid larvae	5.4	2.2	3.3	2.2	1.9	2.9	2.0	4.3
Dipt.-chironomid pupae	.	.	.	.	0.1	0.8	0.4	.
Dipt.-mosquito adult	0.1	0.6	0.3	0.0	0.1	.	.	.
Dipt.-mosquito larvae	0.0	.	0.0	0.0	.	0.0	0.0	0.0
Dipt.-mosquito pupae	.	.	.	.	.	.	.	.
Dipt.-phantom midge adult	.	.	.	.	.	.	.	.
Dipt.-phantom midge larvae	4.8	13.7	5.2	0.6	8.3	4.8	5.0	14.9
Dipt.-phantom midge pupae	3.8	4.1	3.7	0.9	1.7	0.9	0.8	2.6
Dipt.-Dixidae adult	.	.	.	0.0	.	0.1	.	.
Diptera	.	.	.	.	.	.	.	.
Eph.-mayfly adults	.	.	.	.	0.1	.	.	.
Eph.-mayfly nymphs	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1
Gastropoda-snail	0.1	.	0.0	0.0	.	0.0	.	.
Gastropoda-egg	.	.	.	.	.	0.0	.	.

Table 19. Lower Roanoke River zooplankton contribution (% by biomass, continued).

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Hemiptera	.	.	.	.	.	.	.	.
Hemiptera-Belostomatidae	.	.	.	.	.	.	.	.
Hemiptera-Corixidae	.	.	.	.	.	.	0.0	0.1
Hemiptera-Gerridae	.	.	.	.	.	0.0	.	.
Hirudinea	.	.	.	0.6	0.1	.	.	.
Hydra	0.5	0.0	0.2	1.9	2.1	2.4	0.5	1.3
Hydra - medusa	.	.	.	.	.	.	.	.
Hymenoptera-ant	0.0	.	.	.	.	0.1	.	0.1
Hymenoptera-diving wasp	0.0	0.0	0.1	0.0	.	0.0	.	0.0
Isopoda	.	0.0	.	.	0.0	0.0	0.0	.
Megalopt.-alderfly larvae	.	.	0.2	.	.	.	.	0.2
Mysidacea - Mysis shrimp	0.0	.	.	.	.	.	.	.
Mysidacea - Mysis zoea	.	.	.	.	.	.	.	.
Nematoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odonata	.	.	.	.	.	.	.	.
Oligo.-*Aeolosoma*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oligo.-*Dero*	0.0	.	.	0.0	0.0	0.0	0.0	0.1
Oligo.-*Stylaria*	0.4	0.1	.	0.4	0.3	0.6	0.4	0.6
Ostracoda	0.4	0.8	0.3	0.1	0.2	0.4	0.2	0.6
Plecoptera adult	.	.	.	.	.	.	.	.
Plecoptera nymph	.	.	.	.	.	.	.	.
Polychaeta	0.0	.	0.0	.	0.0	.	.	.
Rotifer - colonial	.	.	.	0.9	.	0.4	0.1	1.3
Rotifer - single	.	.	.	0.0	0.0	0.0	0.0	0.0
Spongillafly adult	.	.	.	.	.	.	.	.
Spongillafly larvae	0.1	0.0	.	0.2	0.0	0.1	.	.
Tanaid	.	.	.	.	.	.	.	.
Tardigrada	.	.	.	.	.	.	.	.
Thysanoptera (thrip)	.	.	.	.	.	.	.	.
Tubellaria	.	.	.	.	.	.	.	0.1
Total average biomass (g/m^3)	121	54	46	136	41	66	71	28
(n) Total samples	131	178	179	163	171	198	149	140

Table 20. Relative contribution (% using biomass) of each taxonomic group to the spring zooplankton community of Batchelor Bay (Stations 13-16), North Carolina, 1984-1991. Period (.) = not observed in samples, or no weight estimate available.

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Amphipoda-gammarid egg	.	.	.	.	.	0.0	0.0	0.0
Amphipoda - Gammaridae	34.0	14.4	32.0	40.9	57.0	56.7	37.8	31.6
Arachnida	0.4	0.1	.	0.5	0.1	0.3	0.2	0.6
Bivalvia	0.7	0.0	0.0	0.1	0.1	0.0	.	.
Bivalvia-larvae	.	.	.	.	.	0.0	0.0	0.0
Caddisfly adult	0.5	0.1	.	.	0.4	.	.	.
Caddisfly larvae	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.1
Clad. - *Bosmina*	.	3.6	4.5	1.4	2.1	0.6	0.4	3.1
Clad. - *Daphnia*	.	33.4	11.6	12.9	15.3	15.6	31.4	14.1
Clad. - *Leptodora*	2.7	9.4	2.0	0.1	0.1	0.2	0.0	0.4
Cladocera - other	36.9	7.0	15.4	33.6	2.5	13.3	9.7	13.8
Clad.-unid. egg	.	.	.	.	.	0.0	0.0	0.0
Clad.-unid. juvenile	.	.	.	.	.	0.0	0.0	0.0
Coleopt.-Dytiscidae larvae	.	.	.	0.3	.	0.1	0.1	.
Coleopt.-Gyrinidae adult	.	.	.	.	.	.	.	.
Coleopt.-Gyrinidae larvae	.	0.3	0.3	0.2	.	0.2	0.2	.
Coleopt.-Peltodytes larvae	.	.	.	.	.	.	.	.
Coleoptera	.	.	.	.	.	.	.	.
Coleoptera-Elmidae	.	.	.	.	.	.	.	.
Collembola larvae	.	.	.	.	.	.	0.0	.
Copepoda-egg mass	.	.	.	.	.	0.0	0.0	0.0
Copepoda-nauplius	.	.	.	.	.	.	0.0	0.0
Copepoda-*Argulus* sp.	.	.	.	.	.	.	.	.
Copepoda-Calanoida	0.6	1.4	8.1	0.1	1.6	0.1	1.2	1.8
Copepoda-Cyclopoida	7.3	20.6	14.8	5.2	13.9	6.3	10.6	18.1
Copepoda-Harpacticoida	0.1	0.3	0.0	0.0	0.0	.	.	0.0
Copepodids	.	0.0	0.1	.	0.0	0.1	0.0	0.0
Cumacea	.	.	.	.	.	.	.	.
Decapoda - shrimp larvae	.	.	.	.	.	.	.	.
Dipt.-biting midge larvae	0.1	0.0	0.1	0.2	.	0.1	0.1	0.0
Dipt.-biting midge pupae	.	.	.	.	.	.	.	.
Dipt.-chironomid adult	2.9	0.6	0.9	.	0.9	1.1	1.1	1.4
Dipt.-chironomid larvae	1.8	0.4	1.0	1.2	0.8	0.4	1.7	3.9
Dipt.-chironomid pupae	.	.	.	.	.	0.1	0.4	0.2
Dipt.-mosquito adult	.	0.2	0.1	.	.	.	.	.
Dipt.-mosquito larvae	0.0	.	.	0.0	.	.	.	.
Dipt.-mosquito pupae	.	.	.	.	.	.	.	.
Dipt.-phantom midge adult	.	.	.	.	.	.	.	.
Dipt.-phantom midge larvae	5.7	6.3	4.4	0.5	3.8	2.5	3.1	8.0
Dipt.-phantom midge pupae	5.4	1.4	4.0	1.3	0.9	0.9	1.2	0.5
Dipt.-Dixidae adult	.	.	.	.	.	.	.	.
Diptera	.	.	.	.	.	.	.	.
Eph.-mayfly adults	.	.	.	.	.	.	.	.
Eph.-mayfly nymphs	0.0	0.0	0.0	.	0.1	0.0	0.0	0.0
Gastropoda-snail	0.0	.	.	.	.	.	.	.
Gastropoda-egg	.	.	.	.	.	.	.	.

Table 20. Batchelor Bay zooplankton contribution (% by biomass, continued).

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Hemiptera	.	.	.	.	.	.	.	.
Hemiptera-Belostomatidae	.	.	.	.	.	.	.	.
Hemiptera-Corixidae	.	.	.	.	.	.	.	.
Hemiptera-Gerridae	.	.	.	.	.	.	.	.
Hirudinea	.	.	.	.	.	0.1	.	.
Hydra	.	.	0.1	0.8	.	0.5	0.0	.
Hydra - medusa	.	.	.	.	.	.	.	.
Hymenoptera-ant	.	.	.	.	0.1	.	.	.
Hymenoptera-diving wasp	0.0	0.0	0.1	0.1	.	0.0	.	.
Isopoda	.	0.0	.	.	0.1	0.0	0.0	0.1
Megalopt.-alderfly larvae	.	.	.	.	.	.	.	.
Mysidacea - Mysis shrimp	.	.	.	.	.	.	.	.
Mysidacea - Mysis zoea	.	.	.	.	.	.	.	.
Nematoda	0.0	.	.	.	.	0.0	.	0.0
Odonata	.	.	.	.	.	.	.	.
Oligo.-*Aeolosoma*	0.0	0.0	0.0	0.0	.	0.0	0.0	0.0
Oligo.-*Dero*	0.0	.	.	0.0	.	.	.	.
Oligo.-*Stylaria*	0.4	0.0	.	0.3	0.0	0.4	0.5	0.5
Ostracoda	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.3
Plecoptera adult	.	.	.	.	.	.	.	.
Plecoptera nymph	.	.	.	.	.	.	.	.
Polychaeta	0.0	.	.	.	.	.	.	.
Rotifer - colonial	.	.	.	0.4	.	0.0	0.0	1.1
Rotifer - single	.	.	.	0.0	0.0	0.0	0.0	0.0
Spongillafly adult	.	.	.	.	.	.	.	.
Spongillafly larvae	0.0	0.1	.	.	.	.	.	.
Tanaid	.	.	.	.	.	.	.	.
Tardigrada	.	.	.	.	.	.	.	.
Thysanoptera (thrip)	.	.	.	.	.	.	.	.
Tubellaria	.	.	.	.	.	.	.	0.2
Total average biomass (g/m^3)	169	90	67	77	51	83	97	35
(n) Total samples	44	54	45	47	41	48	45	52

The late season sampling efforts in western Albemarle Sound indicate that the larger but less abundant organisms are important zooplankton biomass contributors. Dipterans, especially phantom midges and chironomids, represented 6-36% of the Sound biomass; an additional 4-20% was contributed by amphipods (Table 21). Copepod biomass (6-56% of the total) contributed a greater percentage to zooplankton than that of cladocerans (5-47%) in most years.

Changing river flows on a daily basis appear to be important in influencing the abundance of a number of taxa within the zooplankton community. Calibrated mathematical models of Roanoke River flow (as of this writing) were still in the development stage by the USGS and unavailable for predicting zooplankton distribution based on flows. A less sophisticated method of assessing river flow effects was to perform a simple correlation analysis of river flow and abundance of individual zooplankton taxa by station. Since river flow is measured 133.6 river miles upstream of the Roanoke River mouth, we compared zooplankton abundance to the daily average river flow for the date of sample (F), and to the flow record of the previous day (F1), the record two days previous (F2), three days previous (F3), and four days previous (F4). Results for selected zooplankton taxa are presented in Table 22.

For several zooplankton taxa, increased abundance was positively correlated with higher river flow. Colonial rotifer abundance was interesting in that the relatively high positive correlation with river flow exhibited better linear correlation with river flow three or four days previous to the sample (Table 22). This relationship suggests that colonial rotifers are perhaps transported from upstream sources to downstream areas, rather than being of a local origin. The correlations with flow are greatest upstream of Plymouth (Stations 2-4) and in the Thoroughfare (Station 5) and adjacent to the Weyerhaeuser paper mill (Station 7), and are lower or not significant in the Middle River (Stations 6 and 9) or Cashie River (Stations 8 and 11). Single rotifers, *Daphnia*, and *Hydra* also exhibit significant positive correlations with increased river flow, but there were no obvious spatial or temporal components in the data (Table 22).

Other selected zooplankton taxa showed an inverse correlation with river flow, suggesting that increased river flow decreases taxa abundance (perhaps either as a diluting mechanism, flushing action, or combination). Cyclopoid copepods exhibited a delta abundance that had greatest negative correlation coefficient values with river flow recorded three to four days previous to the sample (Table 22). Values were highest for Cashie River stations (8, 11), and similar for Middle River stations (6, 9). Calanoid copepod abundance exhibited a greater inverse correlation with river flow on the same day of the sample (F), or one day previous (F1), at Stations 1-4. In the delta, however, the relationship changed such that greatest negative values were with flows three or four days previous to the sample. The densities of harpacticoid copepods and *Bosmina* also have an inverse correlation with river flow (Table 22).

The zooplankton community of the lower Roanoke River, delta, and western Sound appears to be rather complex in both space and time. To determine how the zooplankton communities of the study area were related in species composition and relative abundance, we

Table 21. Percent contribution (% using biomass) of each taxonomic group to the spring zooplankton community of Western Albemarle Sound (Stations 17-32), North Carolina, 1984-1991. Period (.) = not observed in samples, or no weight estimate available.

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Amphipoda-gammarid egg	.		.	.	.	.	0.0	.
Amphipoda - Gammaridae	17.0		9.9	14.9	20.9	16.9	14.3	4.5
Arachnida	0.7		.	0.2	0.0	0.1	0.3	0.3
Bivalvia	.		.	0.1	.	0.0	0.0	0.2
Bivalvia-larvae	.		.	.	.	.	.	0.0
Caddisfly adult	.		.	.	.	.	.	.
Caddisfly larvae	.		.	.	0.0	0.0	0.0	.
Clad. - *Bosmina*			0.1	0.9	0.2	2.2	0.2	0.5
Clad. - *Daphnia*			2.3	8.1	1.6	10.8	5.4	1.5
Clad. - *Leptodora*	37.0		3.4	20.8	20.7	15.8	19.7	6.9
Cladocera - other	19.2		0.1	2.9	0.5	10.3	11.6	12.0
Clad.-unid. egg	.		.	.	.	0.0	0.0	0.0
Clad.-unid. juvenile	.		.	.	.	0.0	0.0	0.0
Coleopt.-Dytiscidae larvae	.		.	.	.	.	0.0	.
Coleopt.-Gyrinidae adult	.		.	.	.	.	.	.
Coleopt.-Gyrinidae larvae	.		.	0.2	.	.	.	.
Coleopt.-Peltodytes larvae	.		.	.	.	.	.	.
Coleoptera	.		.	.	.	.	.	.
Coleoptera-Elmidae	.		.	.	.	.	.	.
Collembola larvae	.		.	.	.	.	.	.
Copepoda-egg mass	.		.	.	.	0.0	0.0	.
Copepoda-nauplius	.		0.0	.	.	.	.	.
Copepoda-*Argulus* sp.	.		.	.	.	.	.	0.0
Copepoda-Calanoida	0.6		37.9	0.5	2.0	0.6	0.4	0.5
Copepoda-Cyclopoida	4.1		9.6	41.3	45.0	36.3	35.5	56.6
Copepoda-Harpacticoida	0.1		0.0	0.0	.	.	.	0.0
Copepodids	.		0.0	.	0.0	.	0.0	0.0
Cumacea	.		.	.	.	.	0.0	.
Decapoda - shrimp larvae	.		.	.	.	.	.	.
Dipt.-biting midge larvae	0.5		0.1	0.0	.	0.0	.	0.0
Dipt.-biting midge pupae	.		.	.	.	.	.	.
Dipt.-chironomid adult	2.8		1.6	.	0.9	.	0.6	0.3
Dipt.-chironomid larvae	0.3		.	0.2	0.2	0.1	1.6	0.4
Dipt.-chironomid pupae	.		.	.	0.1	0.2	.	0.7
Dipt.-mosquito adult	.		0.6	.	.	.	.	.
Dipt.-mosquito larvae	.		.	.	.	.	.	.
Dipt.-mosquito pupae	.		.	.	.	.	.	.
Dipt.-phantom midge adult	.		.	.	.	.	.	.
Dipt.-phantom midge larvae	13.4		33.7	8.5	7.1	6.2	6.6	12.4
Dipt.-phantom midge pupae	4.5		0.7	1.3	0.6	.	0.1	2.9
Dipt.-Dixidae adult	.		.	.	.	.	.	.
Diptera	.		.	.	.	.	.	.
Eph.-mayfly adults	.		.	.	.	.	.	.
Eph.-mayfly nymphs	.		.	.	0.0	0.0	1.5	0.0
Gastropoda-snail	.		.	.	.	.	.	.
Gastropoda-egg	.		.	.	.	.	.	.

Table 21. Western Albemarle Sound zooplankton contribution (% by biomass, continued).

Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
Hemiptera	.		.	.	.	.	.	.
Hemiptera-Belostomatidae	.		.	.	.	.	.	.
Hemiptera-Corixidae	.		.	.	.	.	0.1	.
Hemiptera-Gerridae	.		.	.	.	.	.	.
Hirudinea	.		.	.	.	.	.	.
Hydra	.		0.1	0.0	.	.	0.0	.
Hydra - medusa	.		.	.	.	.	.	.
Hymenoptera-ant	.		.	.	.	.	.	.
Hymenoptera-diving wasp	.		.	0.0	.	.	.	.
Isopoda	.		.	.	.	0.2	0.3	0.1
Megalopt.-alderfly larvae	.		.	.	.	.	.	.
Mysidacea - Mysis shrimp	.		.	.	.	.	.	0.0
Mysidacea - Mysis zoea	.		.	.	.	.	.	.
Nematoda	.		.	.	.	.	0.0	0.0
Odonata	.		.	.	.	.	.	.
Oligo.-*Aeolosoma*	.		.	.	.	.	0.0	.
Oligo.-*Dero*	.		.	.	.	.	.	.
Oligo.-*Stylaria*	.		.	0.0	.	0.2	0.0	0.0
Ostracoda	0.1		0.0	0.0	0.1	0.0	0.0	0.0
Plecoptera adult	.		.	.	.	.	.	.
Plecoptera nymph	.		.	.	.	.	.	.
Polychaeta	.		.	.	.	.	.	.
Rotifer - colonial	.		.	.	.	.	0.0	0.1
Rotifer - single	.		.	.	0.0	0.0	0.0	0.0
Spongillafly adult	.		.	.	.	.	.	.
Spongillafly larvae	.		.	.	.	.	.	.
Tanaid	.		.	.	.	.	.	.
Tardigrada	.		.	.	.	.	.	.
Thysanoptera (thrip)	.		.	.	.	.	.	.
Tubellaria	.		.	.	.	.	.	.
Total average biomass (g/m^3)	139	.	40	84	51	97	106	71
(n) Total samples	6	0	20	65	43	31	62	63

Table 22. Significant (P≤0.05) Pearson correlation coefficients for selected zooplankton taxa and Roanoke River flow (recorded at River Mile 133.6) on the day of sampling (F) and the average daily flow one day previous (F1), two days previous (F2), three days previous (F3), and four days previous (F4) for locations in the lower Roanoke River (Stations 1-4, 7, 10, 12), Middle River (Stations 6, 9), and Cashie River (Stations 5, 8, 11) for the period 1984-1991. Number of sampling efforts in parentheses.

		Station											
Taxonomic group	River flow	1 (91)	2 (84)	3 (81)	4 (86)	5 (101)	6 (119)	7 (117)	8 (133)	9 (127)	10 9135)	11 (116)	12 (119)
Clad. - Bosmina	F	0.25				-0.22	-0.19	-0.24				-0.26	
	F1					-0.22	-0.21	-0.24				-0.27	
	F2					-0.21	-0.22	-0.25				-0.27	
	F3					-0.23	-0.24	-0.27				-0.29	
	F4					-0.23	-0.24	-0.27				-0.29	
Clad. - Daphnia	F		0.28	0.27	0.23	0.26				0.21	0.22		
	F1		0.26	0.26	0.22	0.25				0.21	0.22		
	F2	0.22	0.31	0.27	0.26	0.27				0.20	0.21		
	F3	0.22	0.35	0.27	0.26	0.26				0.19	0.20		
	F4	0.28	0.47	0.29	0.31	0.27				0.20	0.23		
Copepoda-Calanoida	F	-0.26	-0.24	-0.30	-0.26		-0.29	-0.22	-0.25	-0.22	-0.22	-0.34	-0.30
	F1	-0.24	-0.25	-0.30	-0.26		-0.32	-0.21	-0.26	-0.24	-0.24	-0.33	-0.31
	F2		-0.22	-0.28	-0.25		-0.29	-0.21	-0.24	-0.25	-0.26	-0.33	-0.31
	F3			-0.27	-0.23		-0.28	-0.22	-0.28	-0.27	-0.23	-0.34	-0.31
	F4			-0.25			-0.31	-0.23	-0.28	-0.28	-0.21	-0.33	-0.29
Copepoda-Cyclopoida	F						-0.20	-0.20	-0.34	-0.20		-0.38	
	F1						-0.21	-0.20	-0.34	-0.19		-0.39	
	F2						-0.24	-0.25	-0.36	-0.22		-0.40	
	F3						-0.26	-0.25	-0.39	-0.26		-0.41	
	F4						-0.26	-0.24	-0.39	-0.26		-0.41	

Table 22. Pearson correlation coefficients for selected zooplankton taxa and Roanoke River flow (continued).

		Station											
Taxonomic group	River flow	1 (91)	2 (84)	3 (81)	4 (86)	5 (101)	6 (119)	7 (117)	8 (133)	9 (127)	10 9135)	11 (116)	12 (119)
Copepoda-Harpacticoida	F						-0.23	-0.24	-0.24	-0.22		-0.28	-0.22
	F1						-0.22	-0.27	-0.24	-0.20		-0.32	-0.21
	F2						-0.23	-0.29	-0.24	-0.21		-0.32	-0.21
	F3						-0.25	-0.28	-0.27	-0.24		-0.32	-0.18
	F4						-0.25	-0.29	-0.26	-0.24		-0.30	-0.20
Copepodids	F			0.23		0.27							
	F1					0.21							
	F2												
	F3												
	F4												
Hydra	F	0.24	0.35	0.55	0.64	0.69	0.57	0.64	0.44	0.55	0.65	0.46	0.50
	F1		0.33	0.52	0.65	0.72	0.57	0.61	0.47	0.57	0.66	0.46	0.51
	F2		0.24	0.44	0.63	0.72	0.55	0.56	0.46	0.55	0.67	0.46	0.51
	F3			0.40	0.64	0.72	0.53	0.55	0.48	0.57	0.68	0.46	0.52
	F4			0.35	0.62	0.69	0.49	0.55	0.49	0.55	0.68	0.45	0.52
Rotifer - colonial	F	0.32	0.53	0.65	0.55	0.62	0.43	0.59		0.41	0.53		0.43
	F1	0.32	0.55	0.67	0.59	0.67	0.43	0.61		0.43	0.53		0.44
	F2	0.34	0.55	0.67	0.62	0.69	0.46	0.62		0.43	0.52		0.46
	F3	0.36	0.59	0.72	0.66	0.71	0.51	0.66		0.47	0.57		0.49
	F4	0.44	0.69	0.74	0.67	0.73	0.52	0.69	0.18	0.48	0.63		0.50
Rotifer - single	F			0.36		0.38	0.24		0.18				
	F1			0.35		0.38	0.21						
	F2			0.34		0.42	0.20						
	F3			0.35		0.43	0.23						
	F4		0.24	0.38		0.43	0.26						

subjected the data set to cluster analysis (average linkage) and principal component analysis (SAS Institue 1985). Both analyses were performed on the entire data set, and then performed again on a subset of the data that included only the more abundant and potential indicator taxa (49 of 92). The complete set of analyses was performed on both mean density and log normal density.

Results of the analysis on the entire data set as mean densities indicate that there are 10 zooplankton communities within the study area (R^2=0.97). In other words, for each community the relationships among the zooplankton taxa change similarly over time. Since the data encompass eight years, the result represents a long-term general description of the springtime zooplankton within the watershed. Results of the entire data set as log normal densities were similar, but with a lower R^2 value of 0.94.

The 10 zooplankton communities are depicted in Figure 13. The lower Roanoke and Middle Rivers (Stations 1-7, 9, 10, and 12) were grouped as one cluster. This suggests that the upstream zooplankton exert a direct influence on the downstream community. Station 5 at the Thoroughfare also belonged to the river grouping rather than a Cashie River community (Stations 8 and 11), indicating that the Roanoke River exerts more influence within the distributary than the Cashie River. Stations 13 and 14 in Batchelor Bay were similar, but unlike Stations 15 and 16 in the Bay (Figure 13). Station 17 along the south shore adjacent to the Roanoke River mouth has a unique zooplankton community. Stations 20, 21 and 31 (the area between Batchelor Bay and the open waters of the western Sound) were similar. The north shore in the area of Edenton Bay had a similar zooplankton community (Stations 22-24). A western Albemarle Sound community was represented by Stations 18, 26, 28, and 32. Using log normal densities, this western Albemarle Sound community included the Edenton Bay stations (22-24).

Ichthyoplankton

***Morone* Eggs.** Striped bass eggs were collected in the lower Roanoke River in every year except the flood year of 1987 (Table 23). Highest egg densities were always upstream at Stations 1-3 (Appendix E). No eggs were collected from the Middle and Cashie Rivers except in 1990.

In contrast, white perch eggs were collected at many of the river and delta stations during the eight-year study (Table 24). No white perch eggs were present in 1987 samples.

Larval Striped Bass Abundance. In 1984 two peaks of larval striped bass abundance were evident in the Roanoke River during the latter half of May (Figure 14). These two abundance peaks were observed in Batchelor Bay approximately one week later than in the river. This distribution pattern was a function of adult striped bass spawning activity upstream. Hassler and Taylor (1986) reported that nearly 16% of the total estimated egg production was spawned on 15 May followed by an additional 26% on 20-21 May (Table 25). The length frequency distribution (Appendix F) was similar between the River and Bay within a narrow range of

Table 23. Average density (number/100 m^3) of striped bass eggs in the lower Roanoke River, Middle River, and Cashie River, North Carolina, 1984-1991. Number of efforts in parenthesis.

	Roanoke R. mainstem stations							Middle R. stations		Cashie R. stations		
Year	1	2	3	4	7	10	12	6	9	5	8	11
1984	1	1	1	<1	0	0	<1	0	0	0	0	0
	(7)	(7)	(7)	(7)	(11)	(14)	(14)	(11)	(14)	(11)	(14)	(14)
1985	0	0	0	0	0	0	0	0	0	0	0	0
	(7)	(7)	(7)	(7)	(19)	(20)	(20)	(20)	(20)	(15)	(20)	(20)
1986	4	2	2	0	0	0	0	0	0	0	0	0
	(11)	(11)	(11)	(11)	(17)	(17)	(17)	(17)	(17)	(17)	(17)	(17)
1988	12	2	0	0	0	0	0	0	0	0	0	0
	(16)	(15)	(11)	(14)	(15)	(18)	(12)	(15)	(13)	(11)	(15)	(12)
1989	7	<1	1	0	0	0	0	0	0	0	0	0
	(17)	(15)	(15)	(16)	(18)	(18)	(15)	(18)	(17)	(16)	(18)	(15)
1990	29	1	<1	<1	0	0	0	<1	0	<1	0	0
	(10)	(10)	(10)	(9)	(13)	(16)	(14)	(13)	(15)	(10)	(15)	(14)
1991	23	2	<1	0	0	0	0	0	0	0	0	0
	(9)	(9)	(9)	(9)	(11)	(12)	(11)	(11)	(12)	(9)	(12)	(11)

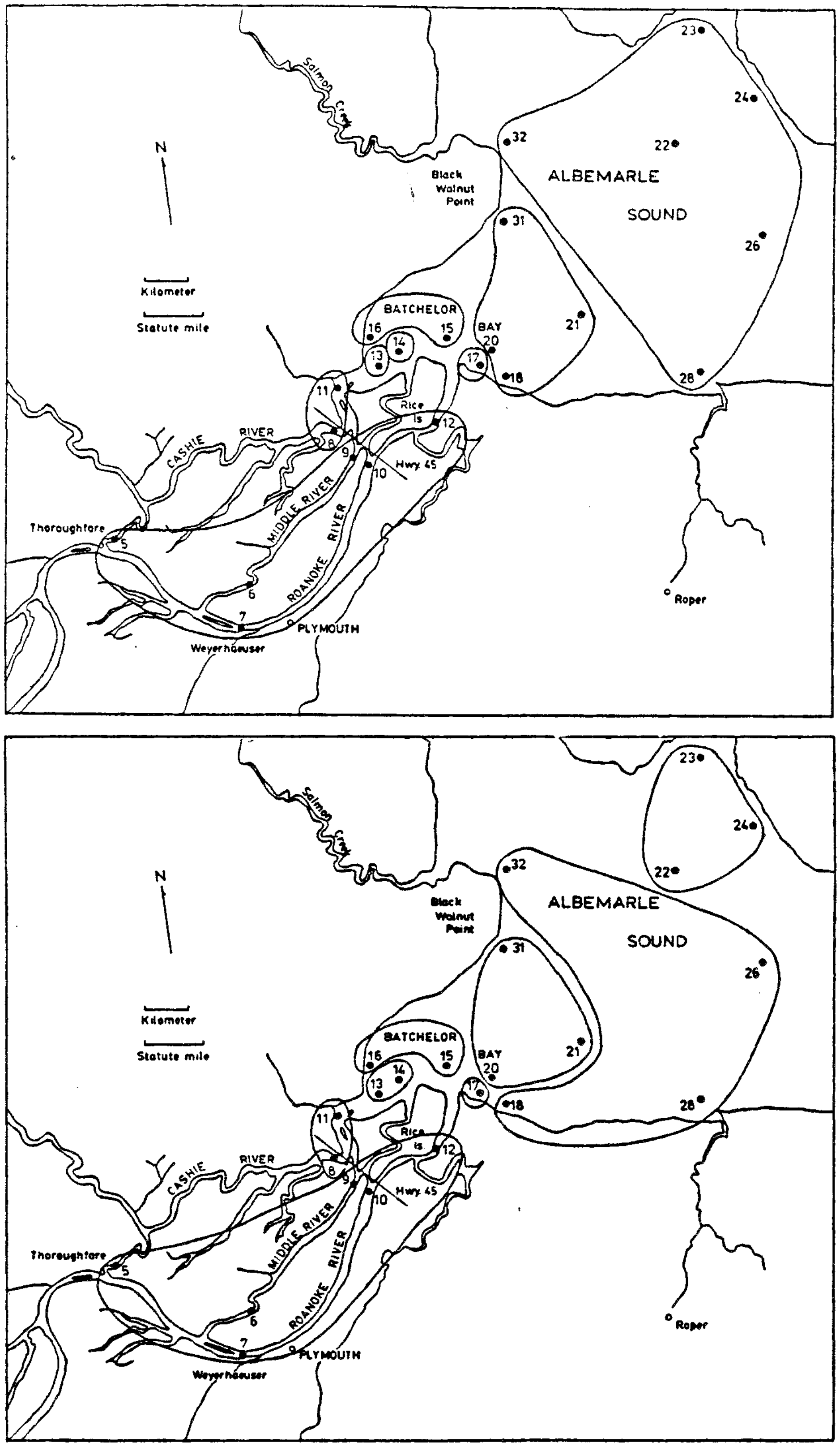


Figure 13. Zooplankton communities of the lower Roanoke River and delta, Batchelor Bay, and western Albemarle Sound based on results of cluster (average linkage) and principal component analyses on zooplankton data from 1984-1991. Top panel = results using log normal density values (R^2=0.94); bottom panel = results using mean densities (R^2=0.97). The River zooplankton group also includes Stations 1-4 upstream.

Table 24. Average density (number/100 m^3) of white perch eggs in the lower Roanoke River, Middle River, and Cashie River, North Carolina, 1984-1991. Number of efforts in parenthesis.

	Roanoke R. mainstem stations							Middle R. stations		Cashie R. stations		
Year	1	2	3	4	7	10	12	6	9	5	8	11
1984	1	5	8	6	3	2	1	<1	0	2	0	<1
	(7)	(7)	(7)	(7)	(11)	(14)	(14)	(11)	(14)	(11)	(14)	(14)
1985	<1	<1	0	0	0	0	0	0	0	0	0	0
	(7)	(7)	(7)	(7)	(19)	(20)	(20)	(20)	(20)	(15)	(20)	(20)
1986	7	9	1	0	0	0	0	0	0	<1	0	0
	(11)	(11)	(11)	(11)	(17)	(17)	(17)	(17)	(17)	(17)	(17)	(17)
1988	15	3	1	<1	3	0	0	<1	0	0	0	0
	(16)	(15)	(11)	(14)	(15)	(18)	(12)	(15)	(13)	(11)	(15)	(12)
1989	2	1	1	1	0	0	<1	<1	0	0	0	0
	(17)	(15)	(15)	(16)	(18)	(18)	(15)	(18)	(17)	(16)	(18)	(15)
1990	<1	0	0	0	0	<1	0	0	<1	0	0	0
	(10)	(10)	(10)	(9)	(13)	(16)	(14)	(13)	(15)	(10)	(15)	(14)
1991	<1	1	<1	0	<1	0	0	<1	0	0	0	0
	(9)	(9)	(9)	(9)	(11)	(12)	(11)	(11)	(12)	(9)	(12)	(11)

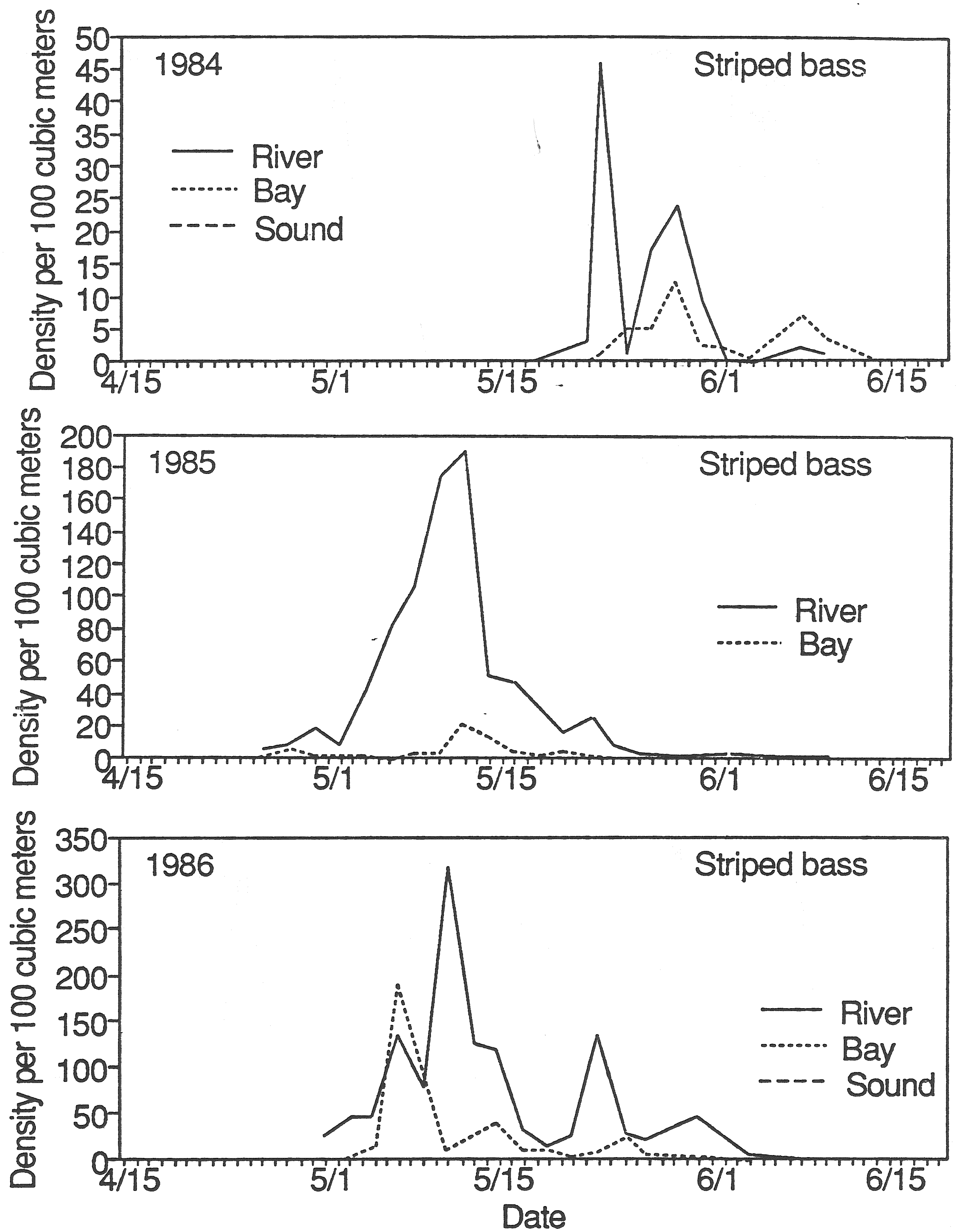


Figure 14. Average density (/100 m^3) of larval striped bass, by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.

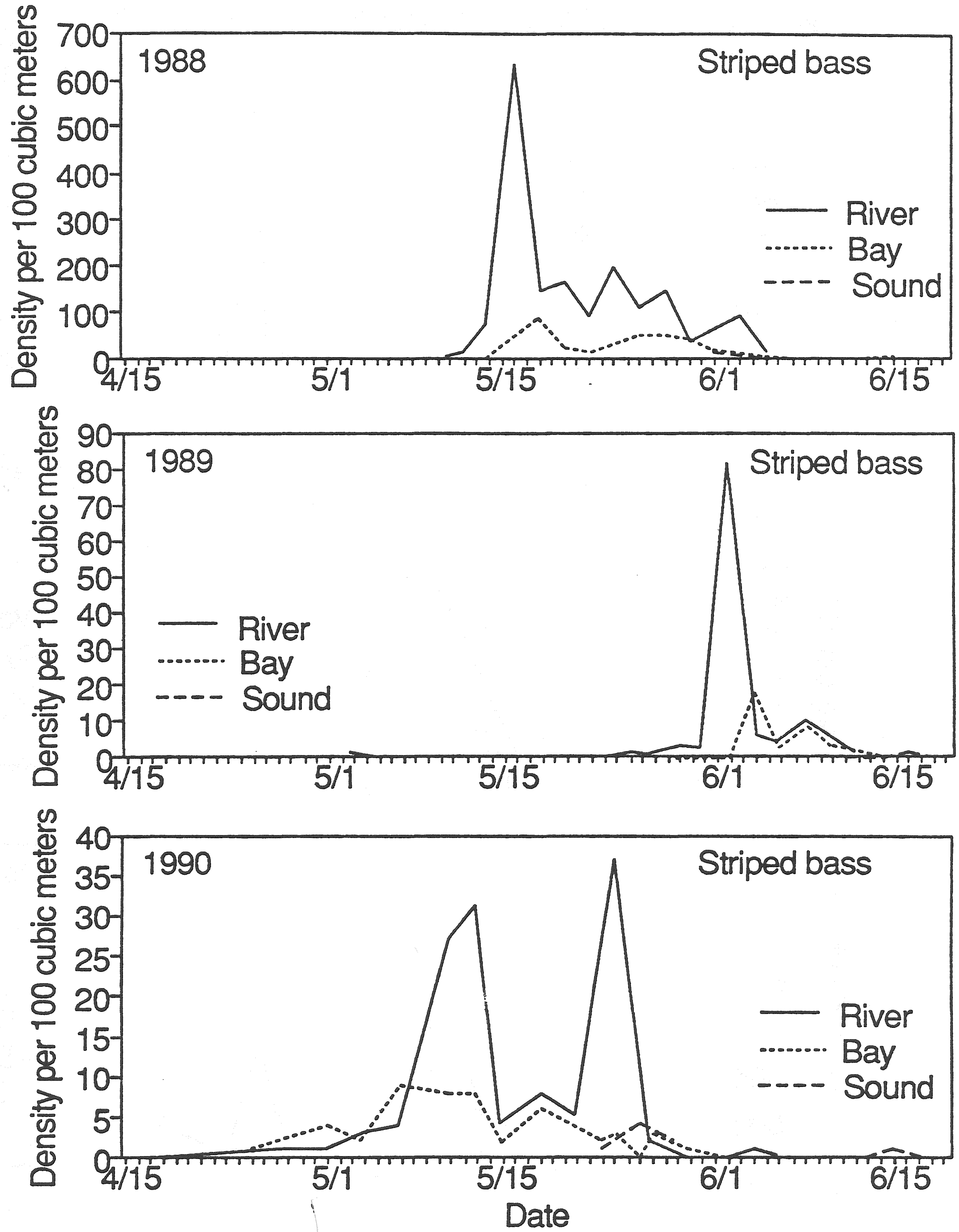


Figure 14. (continued).

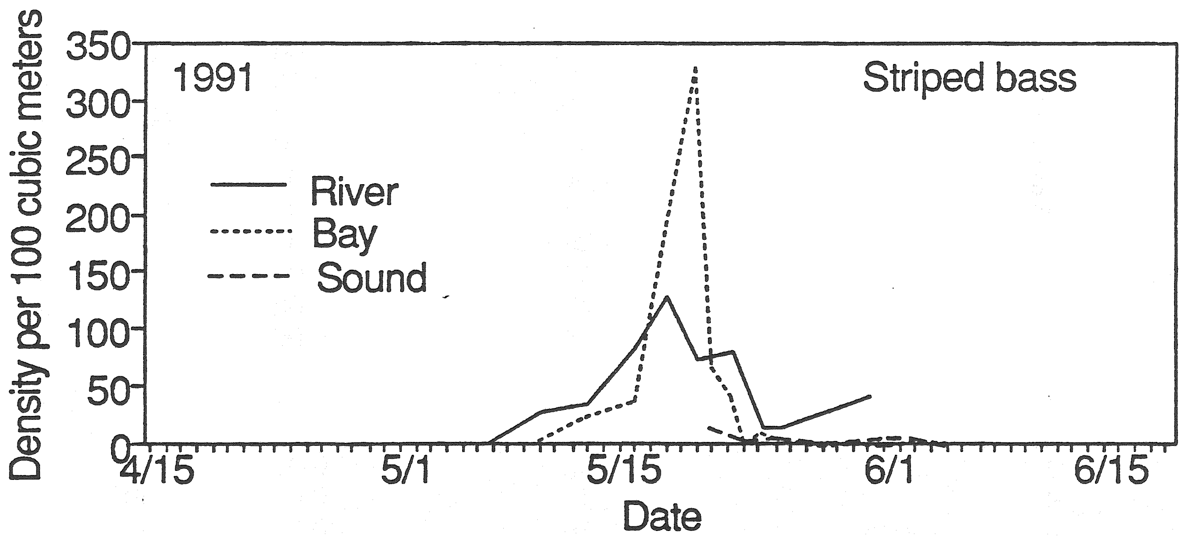


Figure 14. (continued).

Table 25. Spawning activity of adult striped bass, expressed as percent of total estimated egg production, in the Roanoke River downstream of Weldon, North Carolina, 1984-1991 (data from annual reports by Hassler and Rulifson).

Date		1984	1985	1986	1987	1988	1989	1990	1991
Apr	15					0.02			0.00
	16					0.00	0.02	0.00	0.00
	17					0.00	0.00	0.00	0.02
	18					0.00	0.00	0.00	0.00
	19					0.01	0.00	0.00	0.00
	20					0.01	0.00	0.00	0.00
	21					0.00	0.00	0.00	0.00
	22					0.00	0.00	0.00	0.00
	23					0.02	0.00	0.00	0.03
	24					0.00	0.00	0.02	0.05
	25					0.00	0.00	1.23	0.17
	26					0.02	0.00	0.43	0.01
	27					0.00	0.00	1.10	0.00
	28			0.51	0.02	0.00	0.31	0.54	0.21
	29			6.18		0.00	0.14	0.56	0.48
	30			3.06		0.01	0.83	1.05	0.26
May	1			6.27		0.00	1.17	0.94	0.27
	2			7.40		0.06	1.14	3.00	2.30
	3			14.98		0.00	0.00	4.21	0.91
	4			1.47		0.00	0.17	1.58	0.14
	5			0.25		0.01	0.07	1.42	0.77
	6			1.49		0.00	0.00	4.83	2.21
	7			5.66		0.01	0.00	14.80	1.54
	8			12.37		0.01	0.00	3.24	13.73
	9	0.29		3.56		0.21	0.00	7.10	6.44
	10	0.10		0.72		0.58	0.00	20.04	1.44
	11	0.48		1.29		31.67	0.07	3.05	5.82
	12	2.00		1.73	0.18	6.68	0.00	1.84	11.03
	13	6.20		5.08	0.06	1.65	0.00	1.71	4.97
	14	3.91		0.24	0.06	1.64	0.00	2.31	18.77
	15	15.96		0.14	0.18	14.91	0.02	5.04	3.23
	16	0.76		0.29	0.65	6.92	0.00	1.00	3.20
	17	1.17		2.73	0.35	0.88	0.00	3.30	2.74
	18	1.20		14.83	1.70	2.28	0.10	3.52	3.98
	19	3.41		1.99	5.07	1.41	0.41	1.54	1.87
	20	17.02		2.51	11.78	12.58	0.87	0.40	0.35
	21	9.20		0.41	0.76	0.88	1.99	3.55	0.69
	22	3.72		1.01	0.46	1.76	4.39	1.57	1.08
	23	2.36		1.20	2.68	4.04	15.18	0.48	0.66
	24	5.51		1.07	4.39	9.82	11.83	0.24	1.53
	25	6.02		0.70	17.60	0.27	1.93	0.28	1.38
	26	8.56		0.44	10.73	0.84	8.38	0.75	2.23
	27	4.85		0.17	2.49	0.04	25.32	0.58	1.33
	28	1.57		0.07	0.26	0.12	4.18	0.35	1.04
	29	0.62		0.06	0.67	0.37	1.87	0.07	0.88
	30	1.19		0.06	9.19	0.01	1.68	0.00	0.77
	31	0.40		0.06	13.37	0.07	11.82	0.10	0.39

Table 25. Striped bass egg production (continued).

Date		1984	1985	1986	1987	1988	1989	1990	1991
Jun	1	0.04			9.85	0.09	4.32	0.44	0.34
	2	0.16			1.34	0.02	0.81	0.60	0.22
	3	1.03			2.73	0.00	0.13	0.15	0.11
	4	1.30			0.55	0.00	0.26	0.10	0.17
	5	0.18			1.44	0.00	0.16	0.43	0.03
	6	0.08			0.68	0.00	0.16	0.13	0.06
	7	0.20			0.43	0.00	0.11	0.07	0.07
	8	0.34			0.21		0.11	0.00	0.00
	9	0.17			0.12		0.06	0.10	0.01
	10						0.00	0.07	0.03
	11						0.00	0.07	0.02
	12						0.00	0.10	0.04
	13						0.00	0.00	0.00
	14						0.00	0.00	0.00
	15						0.00	0.00	

about 4.0-6.0 mm TL (Figure 15).

In 1985, abundance of striped bass larvae was much greater (approaching 200 larvae/100 m^3) and earlier in the season than that observed in 1984 (Figure 14). Density in Batchelor Bay was lower than would be expected from results obtained in 1984. A shift in the length frequency distribution of larvae in the River suggests that the larvae remained within the lower river for a longer period in 1985. If larvae remained in the river as a result of low flow conditions, this could explain why such a long and extended peak in abundance was present in the river and not observed in the Bay.

In 1986, multiple peaks in abundance were observed with the highest average concentrations in the river just over 300 larvae/100 m^3. Larvae were also abundant in Batchelor Bay and exhibited multiple peaks reflecting that observed in the river. Timing of peak abundance was similar to that of 1985. Spawning peaks were recorded upstream by Hassler and Taylor (1988) on 3 May, 8 May, and 18 May (Table 25). Larval length frequency distribution was similar to that in 1985 with a shift between River and Bay of about 0.5 mm TL (Figure 15). Average river flows were similar but slightly higher than in 1985; high larval abundance may have been due to the low flow conditions retaining the larvae within the lower River.

The flood of 1987 resulted in only 5 striped bass larvae collected throughout the sampling season. Spawning peaks occurred upstream on 20 May (12%), 25-26 May (28%), and 31 May-1 June (23%) (Hassler and Maraveyias 1988). Little recruitment to the forming year class was evident from the annual juvenile abundance index (JAI) conducted in the late summer and fall by Hassler (0.06 fish/trawl) and concurrently by the North Carolina Division of Marine Fisheries (0.30 fish/trawl).

Moderate flow conditions and water temperatures prevailed in 1988. Rulifson (1989) recorded striped bass spawning peaks on 11-12 May (38% of total yearly production), 15-16 May, 20 May, and 23-24 May (Table 25). Multiple peaks in larval abundance were observed in the River throughout the latter half of May and into June (Figure 14). Average densities were considerably higher than in previous years, approaching 650 larvae/100 m^3 in mid-May. The length frequency distribution was smaller in the River than in the Bay or Sound (Figure 15) suggesting movement from the River out into the historical nursery grounds.

Striped bass spawning was late in 1989 due to high stable flows from Roanoke Rapids Reservoir and low water temperatures. Spawning ensued as water temperatures gradually warmed to 18°C in late May (Rulifson 1990). Three major spawning peaks were observed: 23-24 May (27%), 26-27 May (33%), and 31 May-1 June (15%) (Table 25). The closely spaced spawning peaks resulted in one large peak of larval abundance in the River at the end of May followed by a small second peak in June (Figure 14). Similar but small peaks in larval abundance were observed in Batchelor Bay. The length frequency distribution indicates that River larvae were smaller than those in Batchelor Bay and western Albemarle Sound (Figure 15).

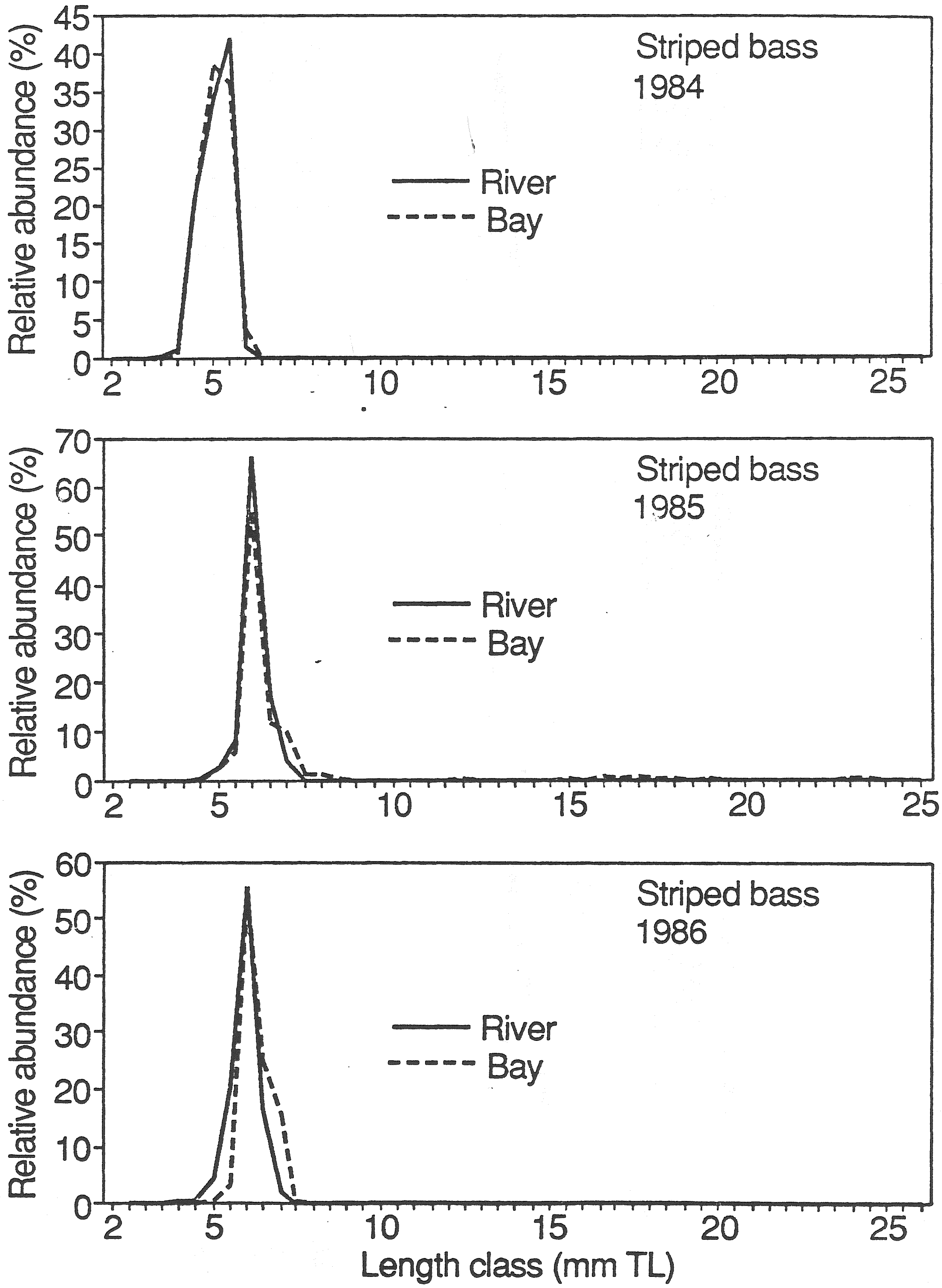


Figure 15. Relative abundance (%) of striped bass larvae, by 0.5-mm TL size class, collected from the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.

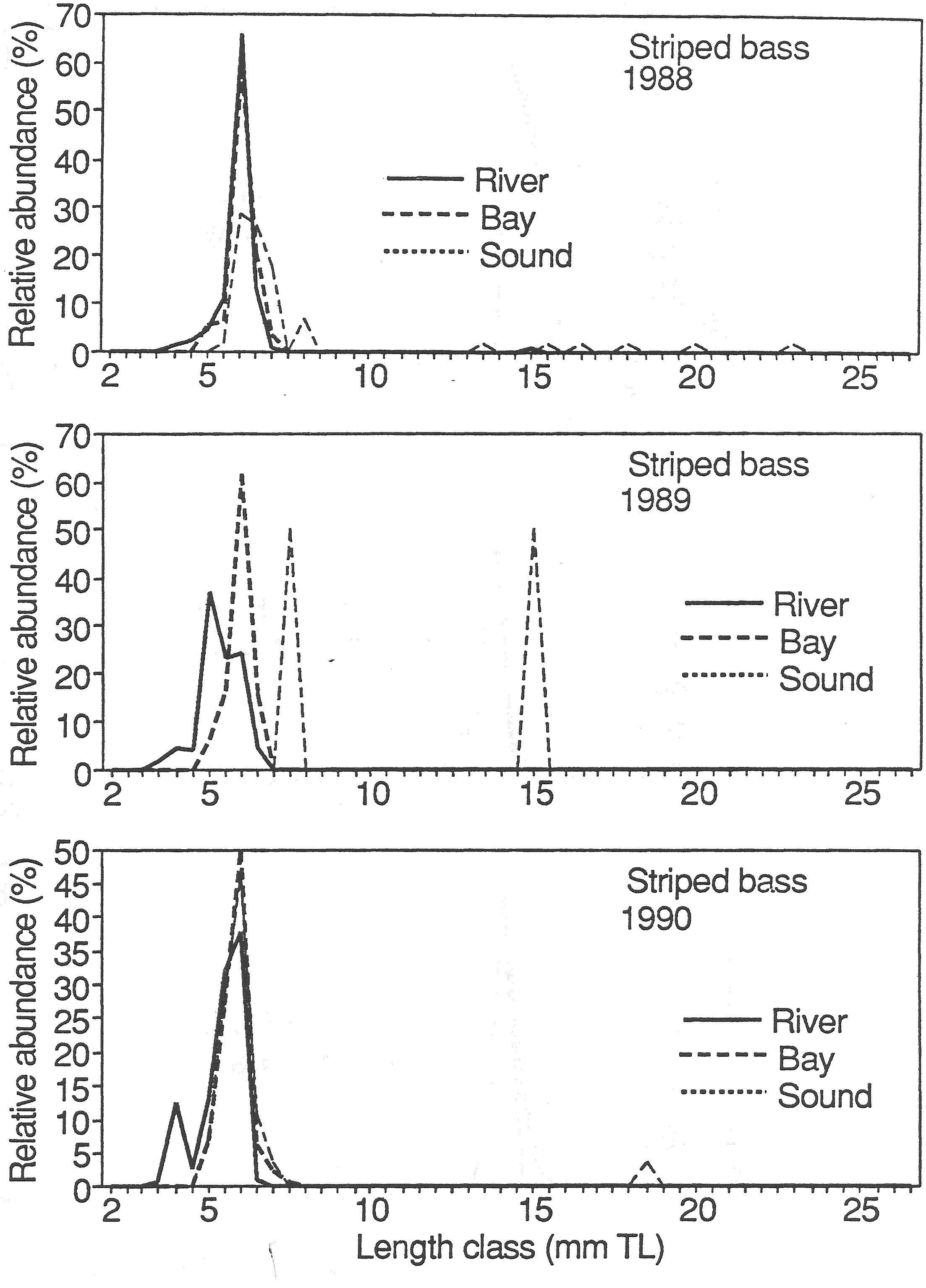


Figure 15. (continued).

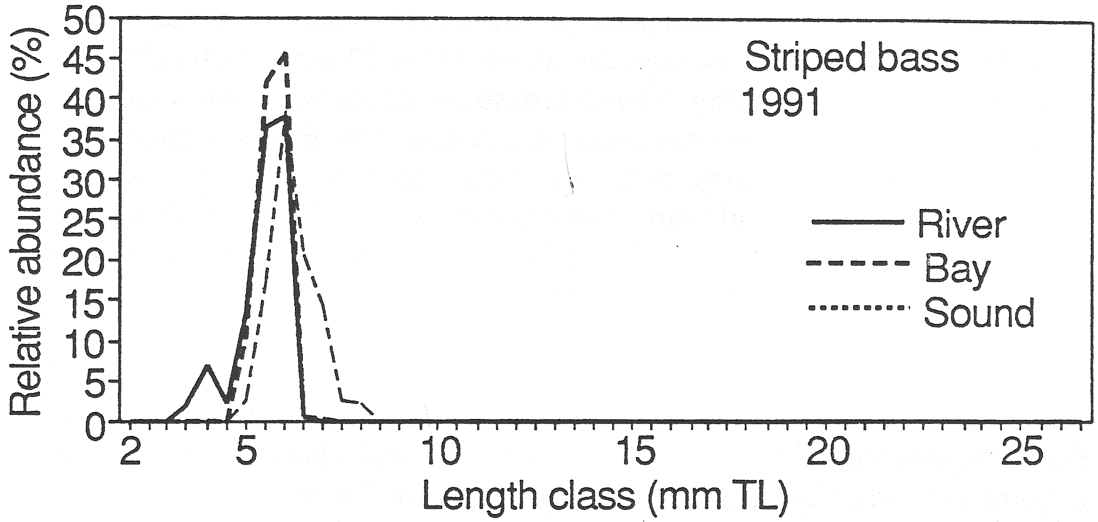


Figure 15. (continued).

In 1990, the overall abundance of striped bass larvae was low at all locations of the study area. Two small peaks in average abundance of 35-40 larvae/100 m^3 about two weeks apart occurred in the middle of May. This pattern seems inconsistent with spawning activity upstream. Two spawning peaks three days apart were recorded by Rulifson (unpublished data): 7 May, 15% of all eggs; and 10 May, 20%. The remainder of the eggs spawned for the season were distributed fairly uniformly throughout the season (Table 25). Again, the length frequency distribution indicated a young cohort of larvae in the river along with a larger group of larvae similar in size to those in Batchelor Bay and western Albemarle Sound (Figure 15).

The pattern of larval striped bass abundance in 1991 was considerably different from that observed in other years. Dates of larval presence in the River were similar, but larval presence in Batchelor Bay was of a fairly short duration with peak abundance exceeding that of the River (Figure 14). Peak spawning activity occurred on 8-9 May (20%), and 11-14 May (41%) (Rulifson 1991). Length frequency data indicate that the Bay larvae were larger than those in the river (Figure 15).

Larval White Perch. White perch larvae were collected in moderate abundance in every year except 1987 (Appendix E). In general, white perch larvae were smaller than larval striped bass (Figures 15 and 16).

First Feeding of Larvae. The location in the River at which larval first feeding occurs is not a direct function of transport time downstream *per se*, but rather the fortuitous interaction of rate of growth and the subsequent functioning of the developing mouth parts. Initially we suspected that feeding would be initiated at a point between the towns of Jamesville and Williamston. However, the first observations of successful feeding (i.e., prey in gut) were most often found in Stations of the Roanoke main stem (Stations 10 and 12), Cashie River (Stations 8 and 11), and Batchelor Bay (Stations 13-14). At the same time, larvae capable of feeding were collected at upstream stations. In 1985 and 1986, successfully feeding larvae were collected in April and early May from the Roanoke Delta (Tables 26 and 27) before any major spawning activity was recorded upstream. Stage 1 larvae (those with a yolk sac) were feeding successfully in the lower River and Delta during low and moderate flow years (1985, 1986, 1988) but apparently are not feeding successfully in the River in years of higher flow (Table 26). Stage 2 striped bass larvae (i.e., no yolk) apparently can feed successfully in most Delta areas early in the season. However, high flows in 1987 and 1990 moved successful feeding larvae out into western Ablemarle Sound (Table 27). Larger *Morone* larvae, which are most likely striped bass but were indistinguishable from white perch, showed similar trends in location of first successful feeding (Table 28). By comparison, white perch larvae are feeding successfully earlier in the season and at most River stations including upstream locations (Table 29).

Larval Feeding Frequency. Estimating the number of larval fish feeding successfully must be interpreted carefully since the pool of sampled fish are only those that survived to be caught, and therefore were successful in a number of ways (e.g., predator avoidance, early foraging). Also, the number of fish examined each year changed greatly. Considering these

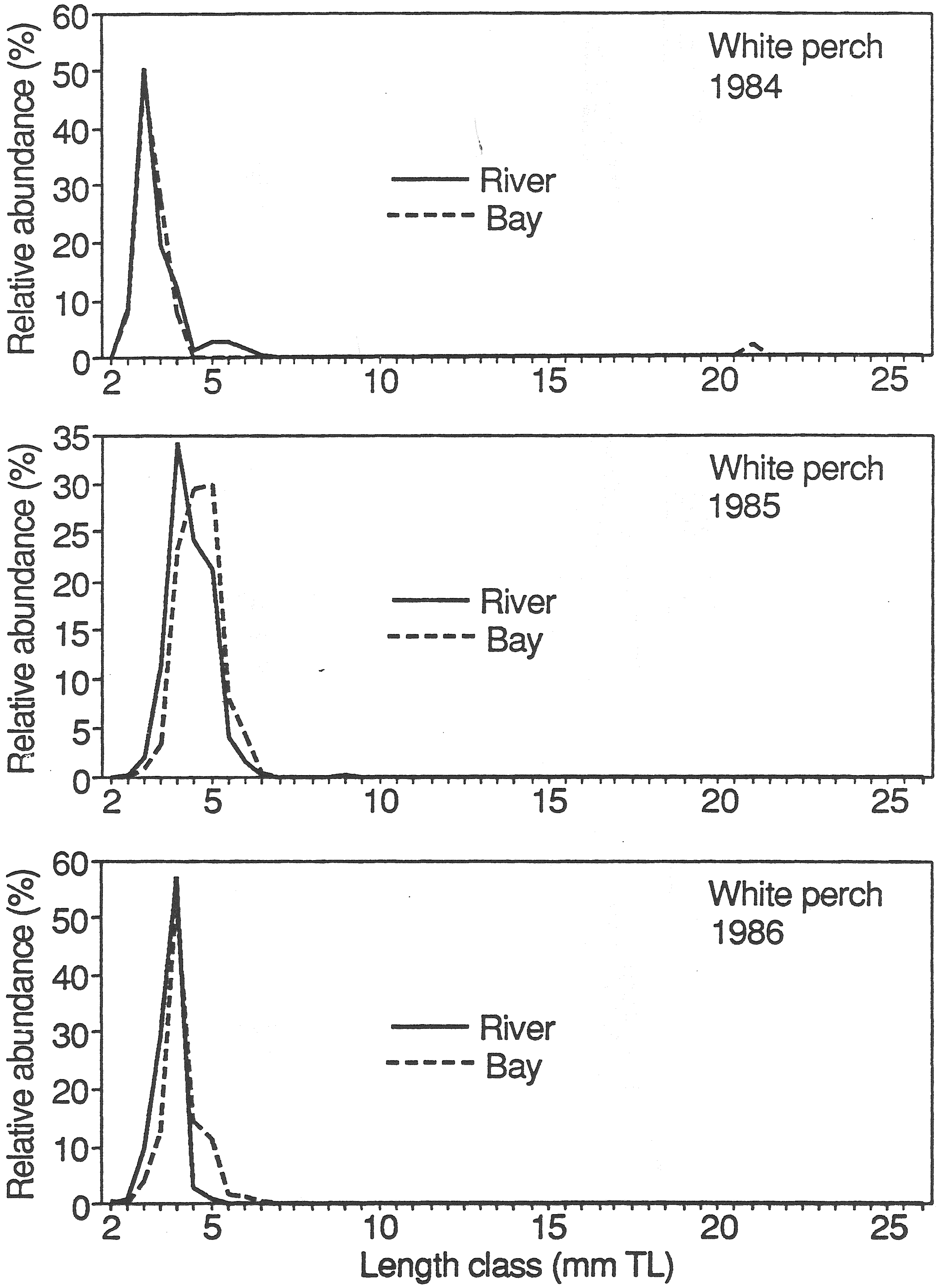


Figure 16. Relative abundance (%) of all white perch larvae, those capable of feeding, and those with prey in stomachs, collected from the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.

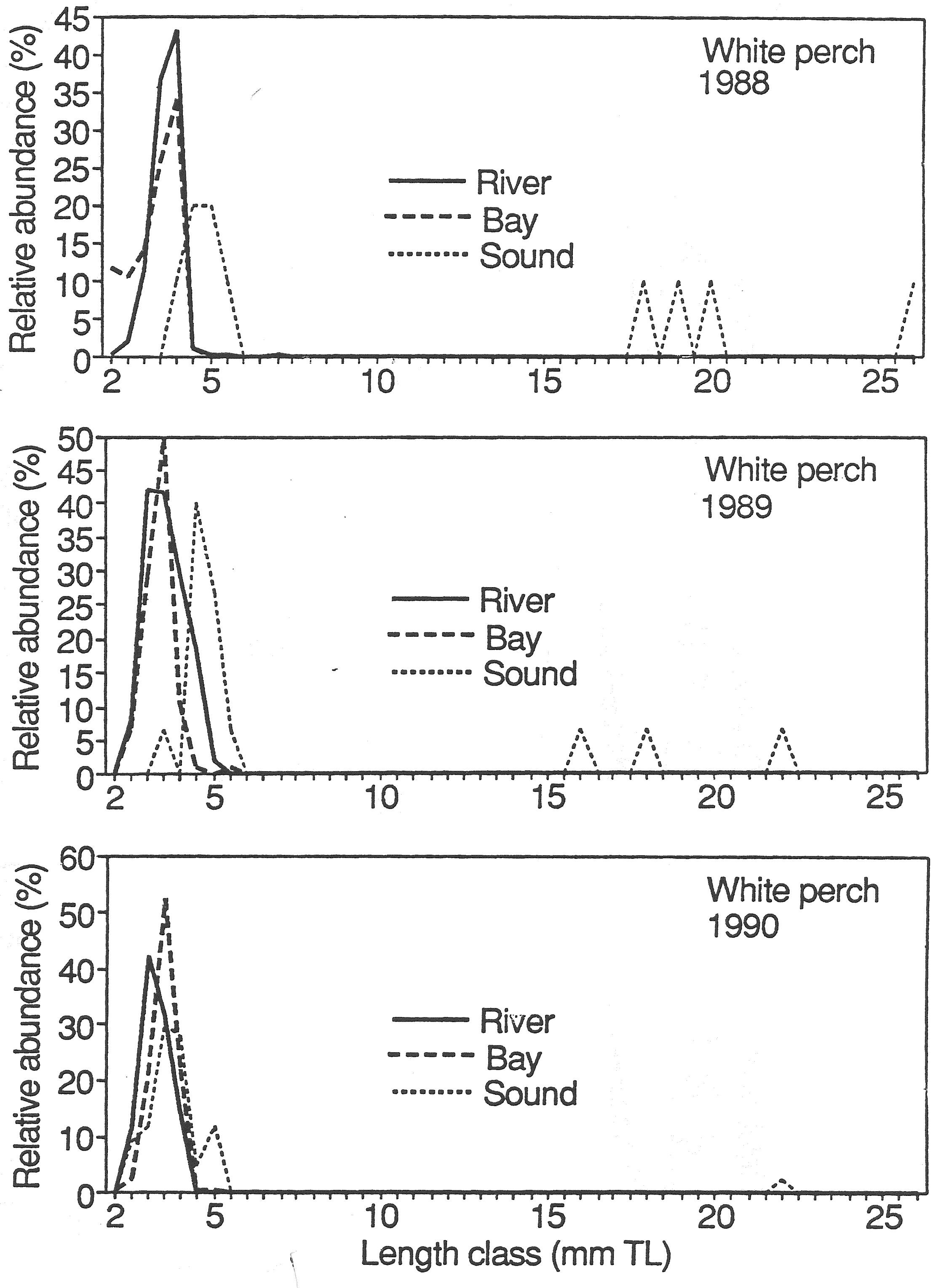


Figure 16. (continued).

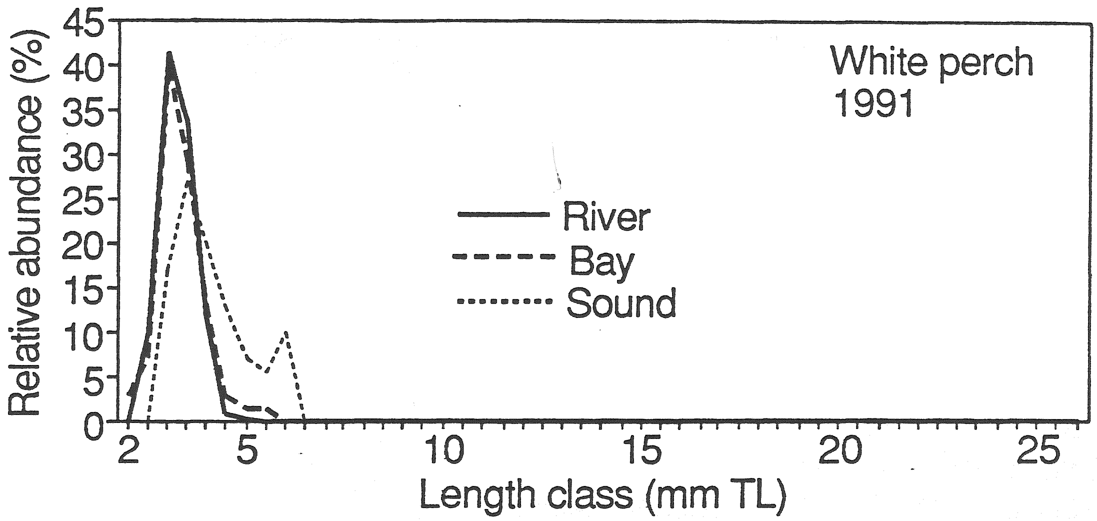


Figure 16. (continued).

Table 26. Date at which feeding by Stage 1 striped bass larvae was first observed in the lower Roanoke River (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound, North Carolina, 1984-1991. Asterisk (*) indicates date of first sample.

	1984	1985	1986	1987	1988	1989	1990	1991
Sta. 1								
Sta. 2								
Sta. 3		May 6						
Sta. 4		May 4						
Sta. 5		May 4						
Sta. 6		Apr 28	May 13					
Sta. 7		Apr 26*	May 13					
Sta. 8		Apr 26*	May 7		May 20			
Sta. 9		Apr 28	May 5		May 20			
Sta. 10		Apr 26*	May 11		May 22			
Sta. 11		Apr 30	May 1*		May 18			
Sta. 12		Apr 26*	May 9		May 24			
Sta. 13		Apr 28*	May 5		May 22			
Sta. 14	Jun 8	May 10	May 5					
Sta. 15		Apr 30	May 7		May 30			
Sta. 16					May 18			
Sta. 17								
Sta. 18								
Sta. 20								
Sta. 21								
Sta. 22								
Sta. 23								
Sta. 24								
Sta. 26								
Sta. 28								
Sta. 31								
Sta. 32								

Table 27. Date at which feeding by Stage 2 striped bass larvae was first observed in the lower Roanoke River (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound, North Carolina, 1984-1991. Asterisk (*) indicates date of first sample.

	1984	1985	1986	1987	1988	1989	1990	1991
Sta. 1								
Sta. 2								
Sta. 3								
Sta. 4		May 4*	Jun 4					
Sta. 5								
Sta. 6		Apr 28*	May 7		May 26			May 18
Sta. 7		Apr 30	May 9					
Sta. 8		May 4	May 7		May 18			May 18
Sta. 9		Apr 28	May 9		May 22			May 18
Sta. 10		Apr 26*	May 11		May 28			
Sta. 11		Apr 26*	May 1*		May 18			May 18
Sta. 12		Apr 28*	May 3		May 24			May 18
Sta. 13		Apr 28*	May 1*		May 18			May 20
Sta. 14		Apr 26*	May 7					
Sta. 15		May 4	May 7		May 22	Jun 10		May 25
Sta. 16		May 18					May 13	
Sta. 17				Jun 13				
Sta. 18					Jun 1*	Jun 10	May 26	May 28
Sta. 20			May 29*		Jun 15*			May 25
Sta. 21			May 29*		Jun 1*		May 26	May 21
Sta. 22							May 29	May 21
Sta. 23					Jun 7*			May 21
Sta. 24			May 29*				Jun 15	May 21
Sta. 26								May 23
Sta. 28					Jun 13		May 26	
Sta. 31					Jun 1*		May 23*	May 21
Sta. 32						Jun 16		May 23

Table 28. Date at which feeding by undifferentiated *Morone* larvae was first observed in the lower Roanoke River (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound, North Carolina, 1984-1991. Asterisk (*) indicates date of first sample.

	1984	1985	1986	1987	1988	1989	1990	1991
Sta. 1								
Sta. 2					May 20			
Sta. 3					May 28			
Sta. 4								
Sta. 5		May 4*						
Sta. 6		Apr 28*						
Sta. 7		Apr 28*						
Sta. 8		Apr 28*	May 1*					
Sta. 9		Apr 28	Jun 4					
Sta. 10		Apr 30						
Sta. 11	Jun 14	Apr 28*	May 1*		Jun 3			
Sta. 12		Apr 28						
Sta. 13		Apr 28*	May 11					
Sta. 14	May 31	Apr 30	May 3					
Sta. 15	Jun 14	Apr 28	May 3		Jun 7			
Sta. 16					Jun 7			
Sta. 17								
Sta. 18					Jun 1*	Jun 14		
Sta. 20			Jun 6					May 25
Sta. 21					Jun 1*	Jun 10*		May 25
Sta. 22					Jun 7*	Jun 10*	May 23*	May 21*
Sta. 23				Jun 9	Jun 7*			May 23
Sta. 24								May 23
Sta. 26					Jun 7*	Jun 14	Jun 13	May 25
Sta. 28					Jun 7*	Jun 14		May 28
Sta. 31					Jun 1*	Jun 10*	Jun 13	May 23
Sta. 32					Jun 1*	Jun 16		May 23

Table 29. Date at which feeding by white perch larvae was first observed in the lower Roanoke River (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound, North Carolina, 1984-1991. Asterisk (*) indicates date of first sample.

	Stage 1		Stage 2	
	1988	1991	1988	1991
Sta. 1	May 20		May 12	
Sta. 2			May 22	
Sta. 3			May 18	
Sta. 4	May 18		May 14	
Sta. 5	May 14		May 18	
Sta. 6			May 14	
Sta. 7	May 20		May 16	
Sta. 8			Apr 21	May 16
Sta. 9			May 11	
Sta. 10			May 12	
Sta. 11			May 12	May 26
Sta. 12			May 18	
Sta. 13			May 20	
Sta. 14				
Sta. 15			May 22	
Sta. 16			May 18	
Sta. 17				
Sta. 18				
Sta. 20				
Sta. 21				
Sta. 22				
Sta. 23				
Sta. 24			Jun 7*	
Sta. 26				
Sta. 28			Jun 13	
Sta. 31			Jun 5	
Sta. 32			Jun 1*	

aspects, more larval striped bass collected from Batchelor Bay and western Albemarle Sound contained prey in stomachs compared to larvae collected from the Roanoke River and Delta (Table 30). In 1986, for example, only 10% of the 4,557 larvae examined from River samples for food habits actually contained prey in stomachs while 45% of the 431 larvae from Bay samples had consumed prey. One possibility for this difference might be that Bay larvae were larger and therefore capable of foraging more effectively. However, examination of the length frequency distribution for 1986 indicates that fish capable of feeding, and those larvae with prey, were not different in size (Figure 17). Examination of 1988 data does show a shift in the length frequency distribution for those fish successful at feeding. Examination of the larger undifferentiated *Morone* larvae, which most likely are striped bass, indicates a greater rate of feeding success in the River and Bay (Table 30). The few white perch larvae examined in 1988 and 1991 also appear to have greater success in feeding than larval striped bass collected in the same area.

Zooplankters Used as Prey. To determine whether the availability of prey items might be a function of fish size, the mouths of a number of larval striped bass were measured to estimate the mouth gape as a function of fish length. Using the average dimensions of selected zooplankton taxa, relationships between fish size (mouth gape) and potential prey were established. Figure 18 depicts these relationships. The average mouth gape of a larval striped bass 5.0 mm TL should allow the fish to consume all zooplankton taxa in food group "A": cladoceran eggs and juveniles, calanoid and harpacticoid copepods, ostracods, copepod eggs and nauplii, copepodites, biting midge larvae, *Aeolosoma*, *Dero*, *Stylaria*, rotifers, nematodes, bivalve larvae, *Hydra*, freshwater polychaetes, and mysid shrimp. Larval striped bass of about 5.8 mm TL should be capable of consuming all prey in food group A plus food group "B": *Bosmina*, *Daphnia*, Sididae, Chydorinae, cyclopoid copepods, chironomid and phantom midge larvae, chironomid adults, caddisfly larvae, gammarid eggs, colonial rotifers, arachnids, snail eggs, and Elmidae. Food group C includes both groups A and B plus chironomid and phantom midge pupae, bivalves, gammarids, turbellarians, and Gyrinidae larvae. Food group D includes groups A through C plus Dixidae adults and Dytiscidae larvae. None of the zooplankton taxa measured fit into food group D (Figure 18). A reexamination of the length frequency distribution shows that most striped bass larvae are within lengths between 5.5 and 6.5 mm TL (Figure 17) and therefore should be capable of consuming zooplankters within food groups A, B, and C.

Bosmina is the zooplankton prey consumed most often by larval striped bass in the lower Roanoke River and Delta (Table 31). Larvae collected in Batchelor Bay, the area characterized by transition zooplankton communities, consumed either *Bosmina* or copepodids as the major food item depending on the year (Table 32). In low flow years 1985 and 1986, copepodids were the major prey; in moderate and higher flow years (1988, 1989, 1990, 1991) *Bosmina* was the dominant prey item. In western Albemarle Sound copepodids represented the major prey in all years (Table 33). The undifferentiated *Morone* larvae also consumed *Bosmina* as the major prey item, but other cladocerans, including *Daphnia*, and biting midge and chironomid larvae and pupae were important was well (Table 34). In Batchelor Bay, undifferentiated *Morone* larvae

Table 30. Percentage of larval striped bass, white perch, and undifferentiated *Morone* with food present in guts (number of fish examined in parentheses) collected from the lower Roanoke River (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.

Species	Area	1984	1985	1986	1987	1988	1989	1990	1991
Striped bass	River	. (0)	49 (1676)	10 (4557)	. (0)	6 (2213)	0 (21)	0 (1)	3 (921)
	Bay	17 (6)	59 (147)	45 (431)	. (0)	38 (312)	6 (18)	29 (7)	2 (771)
	Sound	. (0)	. (0)	100 (3)	100 (1)	53 (3)	67 (3)	73 (15)	47 (194)
White perch	River	.	.	.	.	43 (199)	.	.	21 (28)
	Bay	.	.	.	.	52 (31)	.	.	0 (1)
	Sound	.	.	.	.	80 (10)	.	.	0 (1)
undifferentiated *Morone* sp.	River	2 (45)	53 (1117)	56 (27)	. (0)	75 (4)	. (0)	. (0)	. (0)
	Bay	12 (17)	84 (226)	82 (11)	. (0)	80 (5)	50 (2)	. (0)	. (0)
	Sound	0 (2)	. (0)	100 (1)	38 (8)	91 (101)	40 (35)	100 (5)	85 (46)

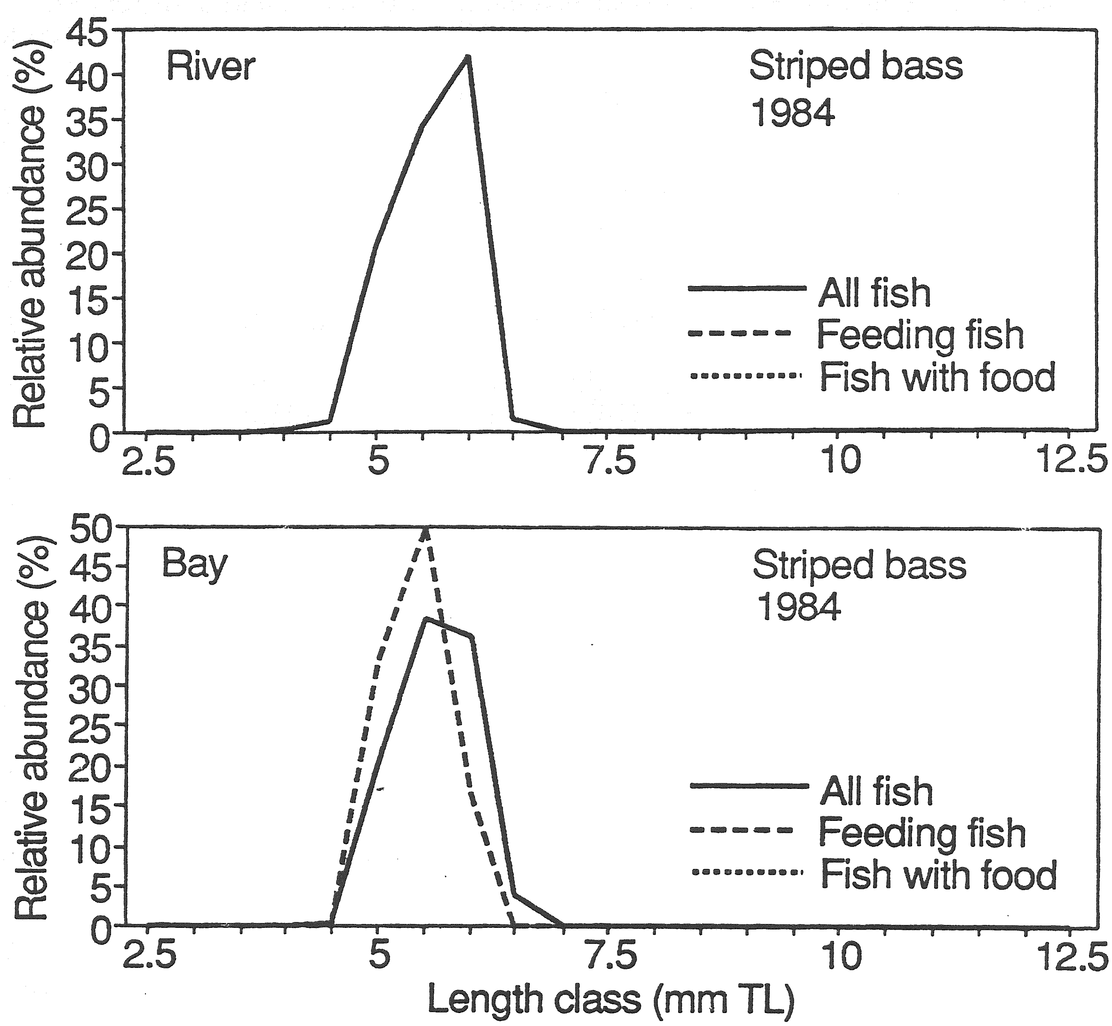
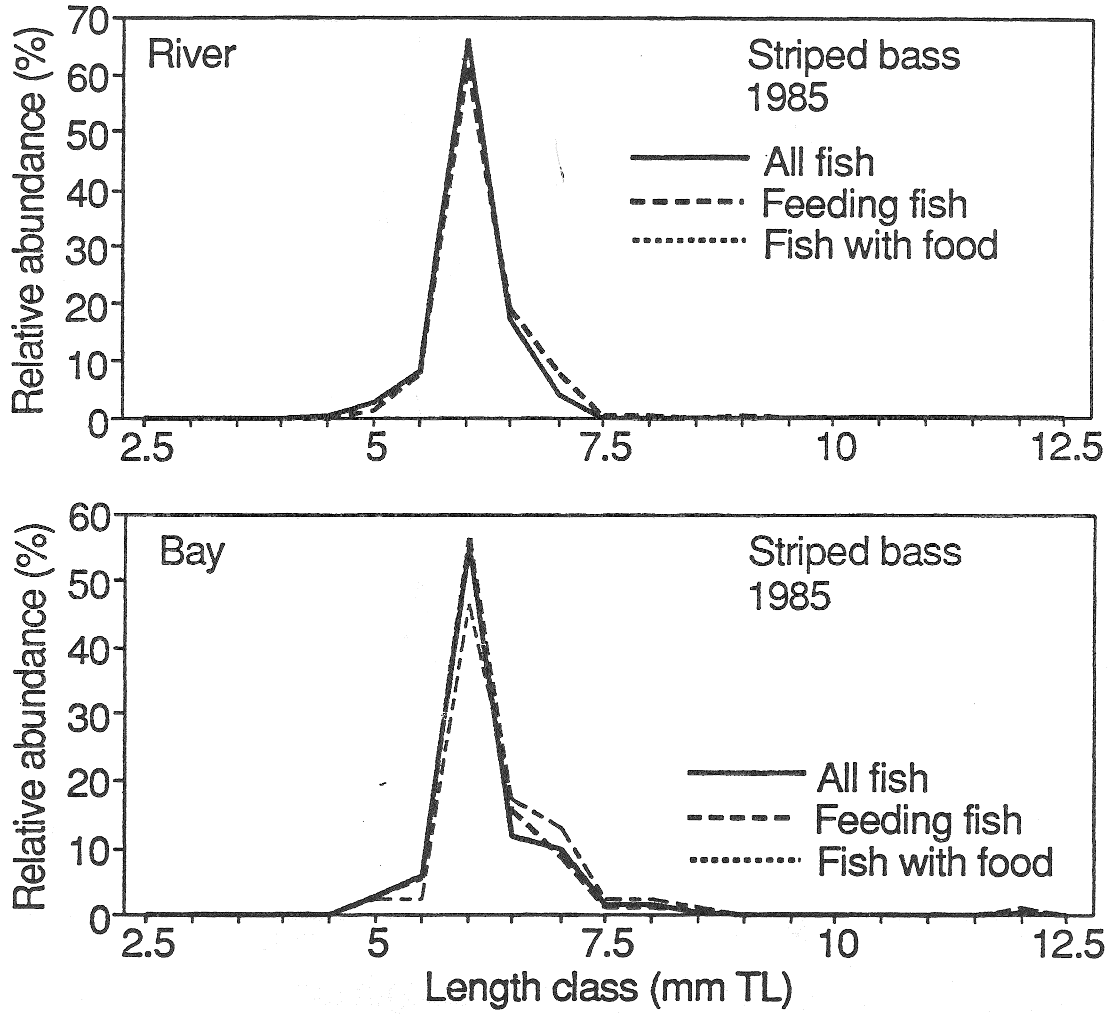


Figure 17. Relative abundance (%) of all striped bass larvae, those capable of feeding, and those with prey in stomachs, collected from the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1991.



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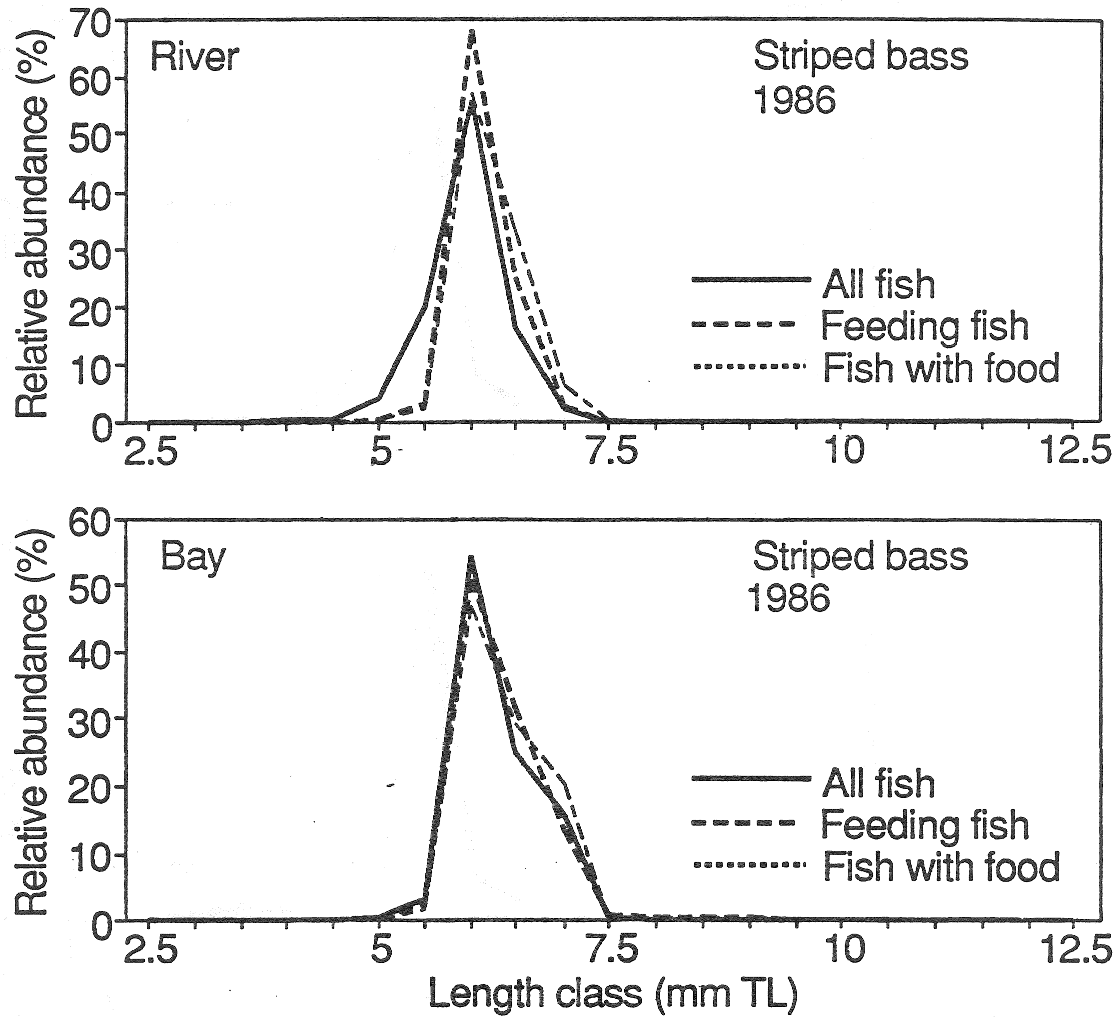

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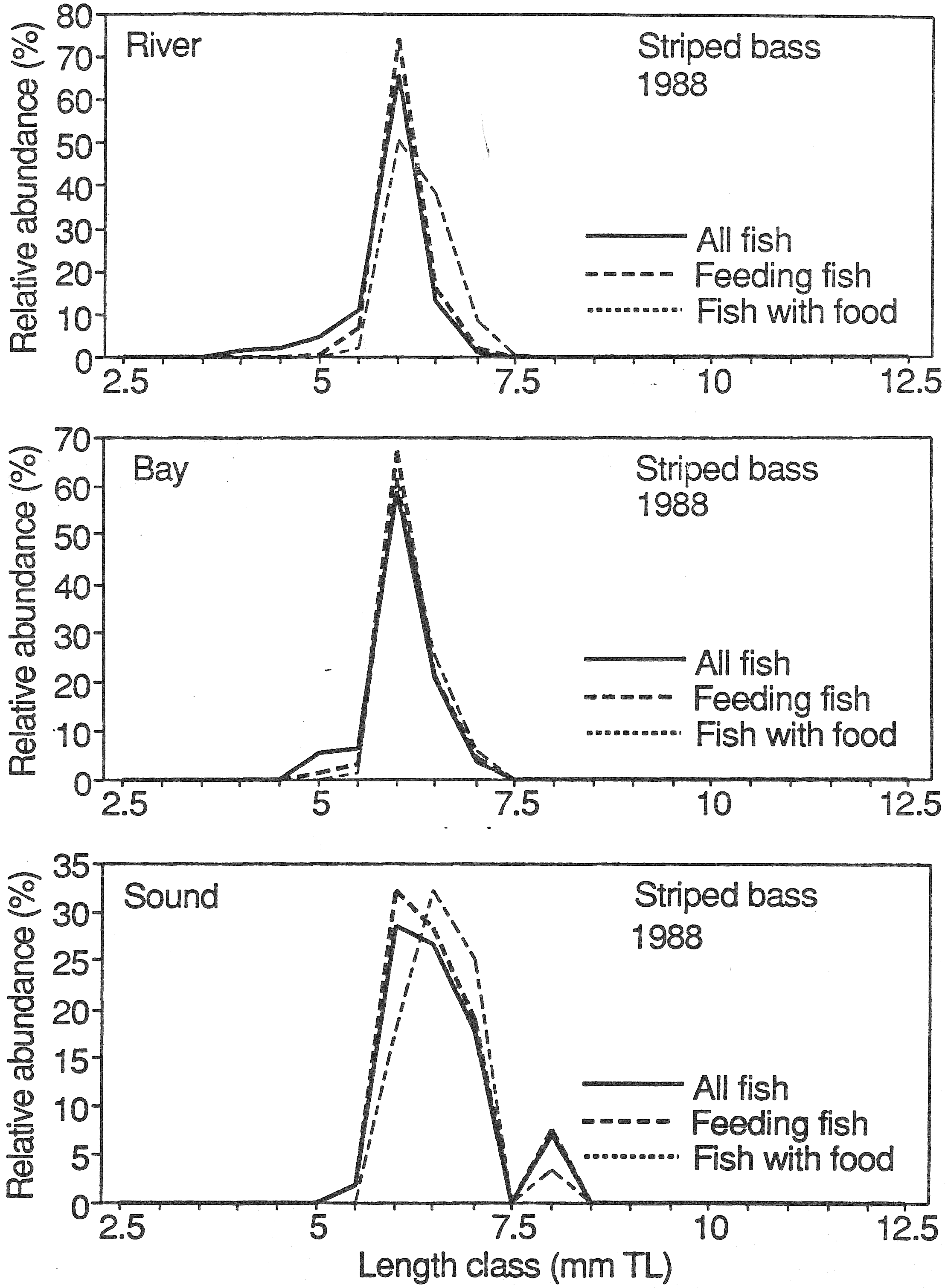

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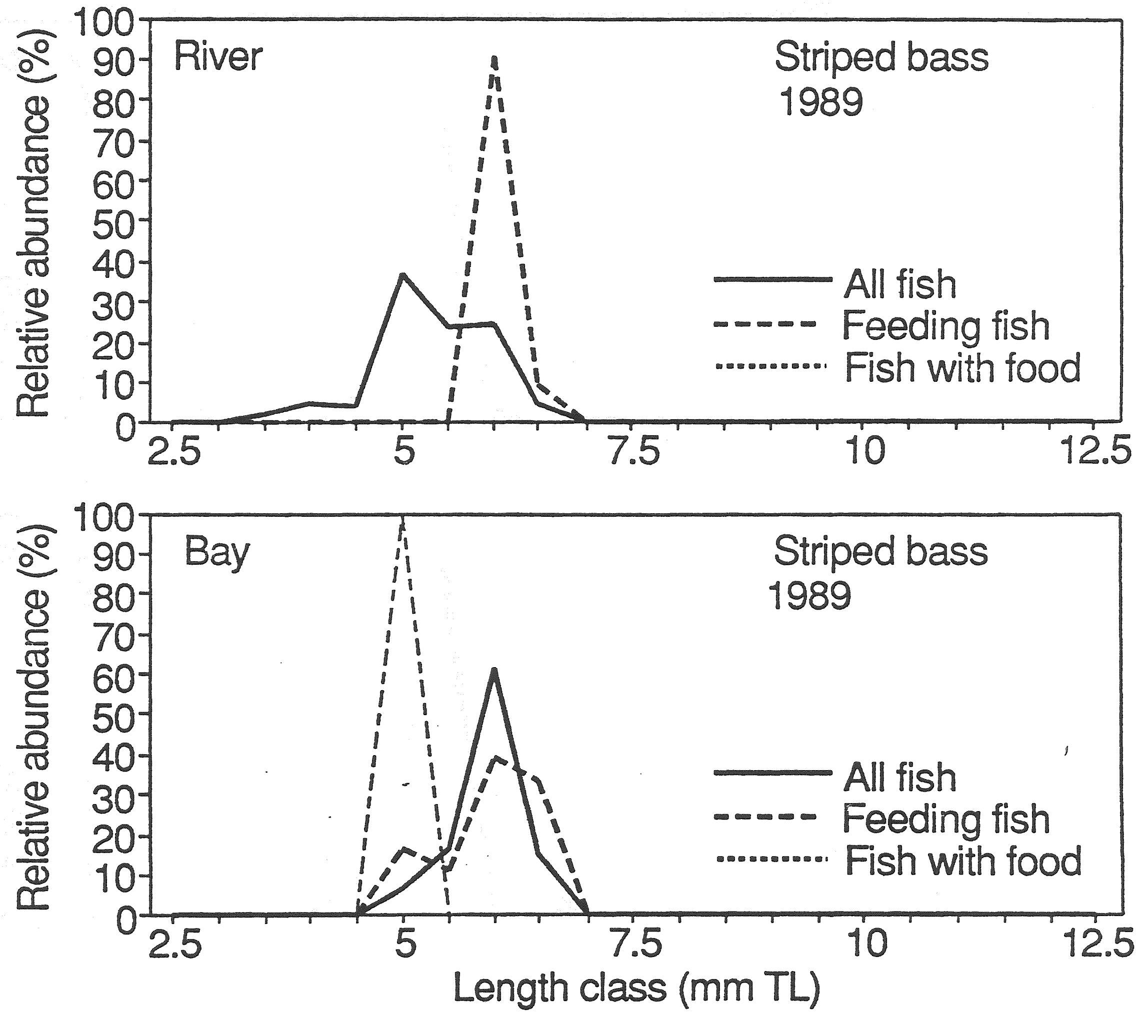

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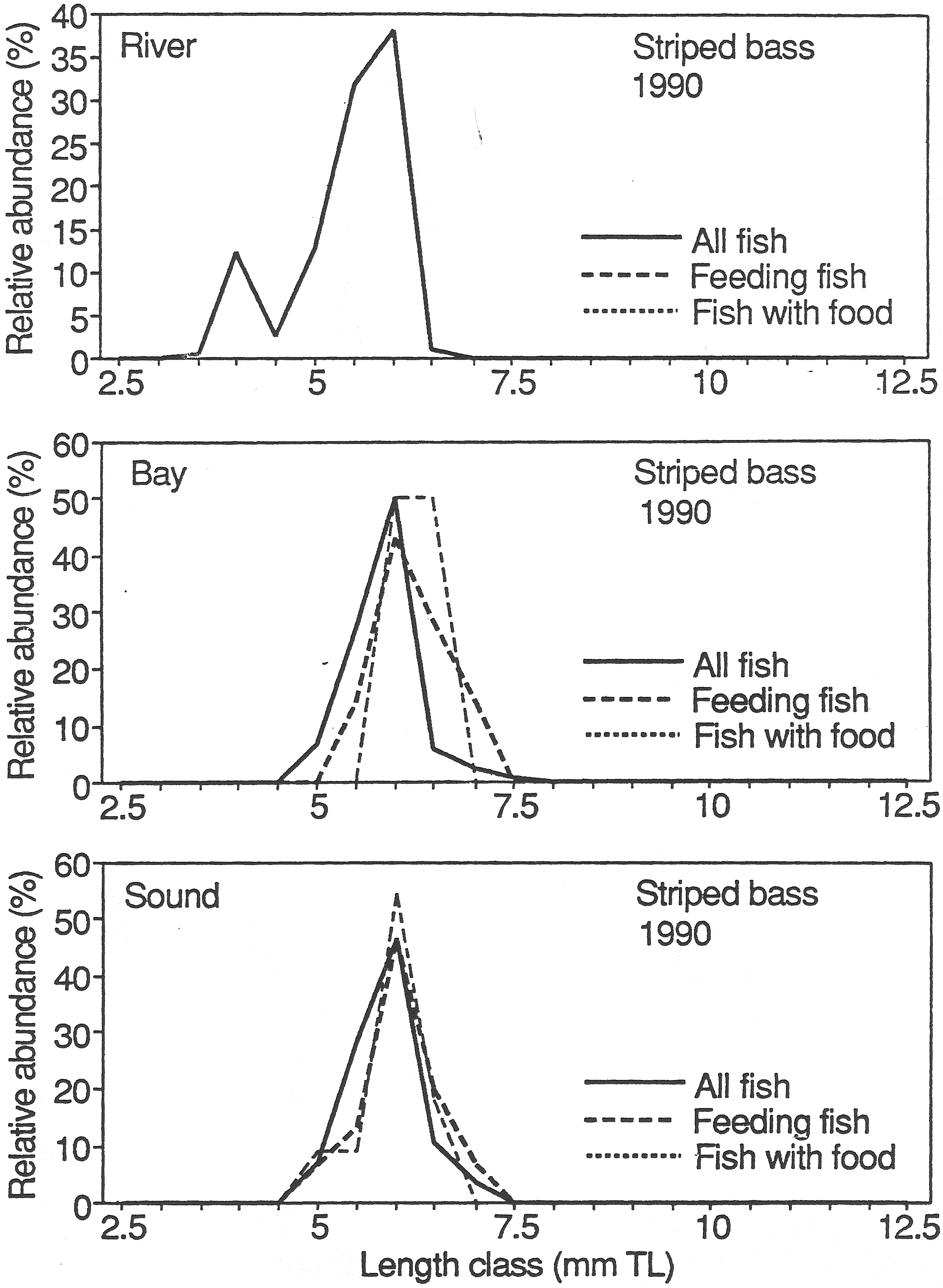

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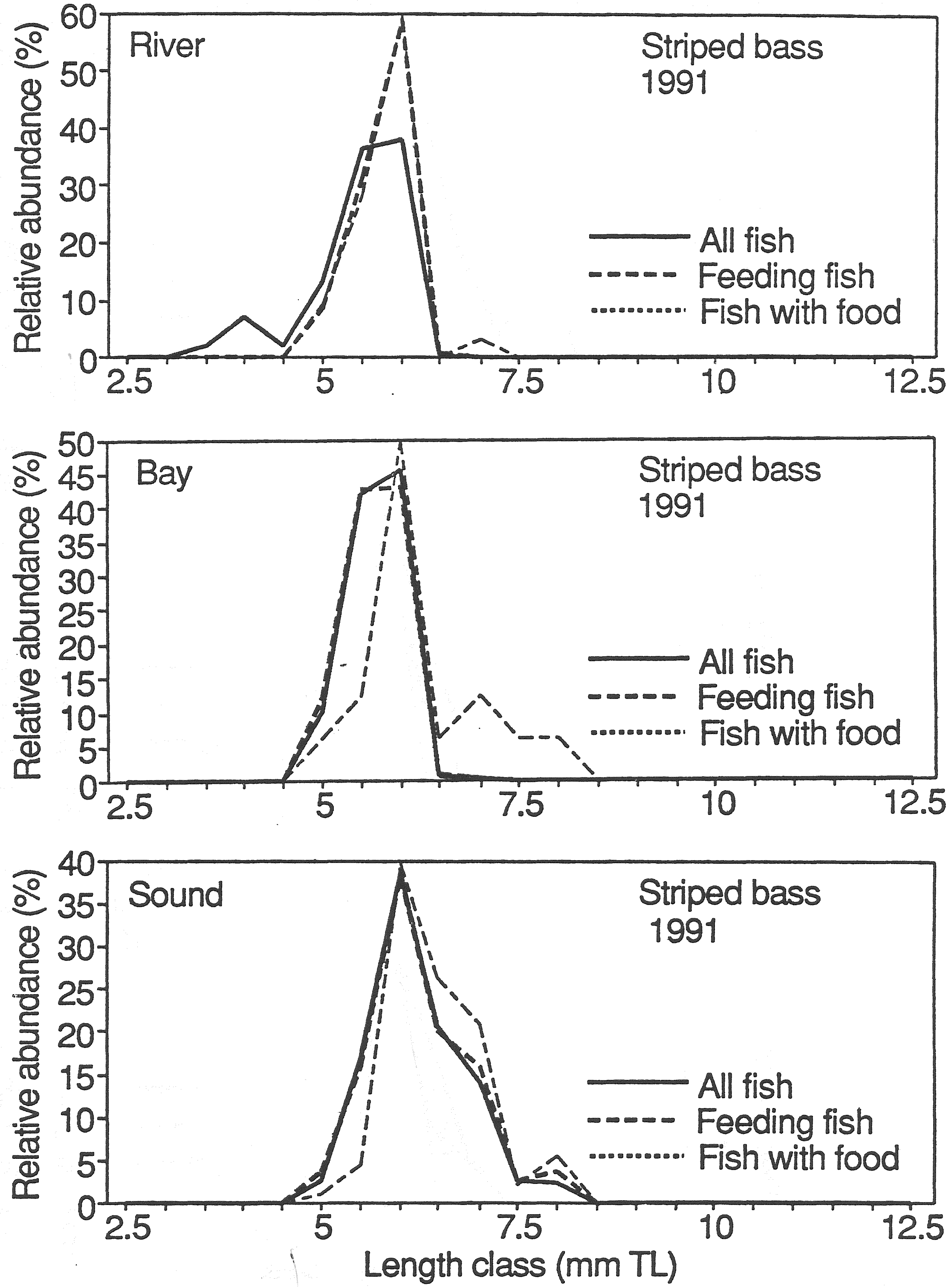

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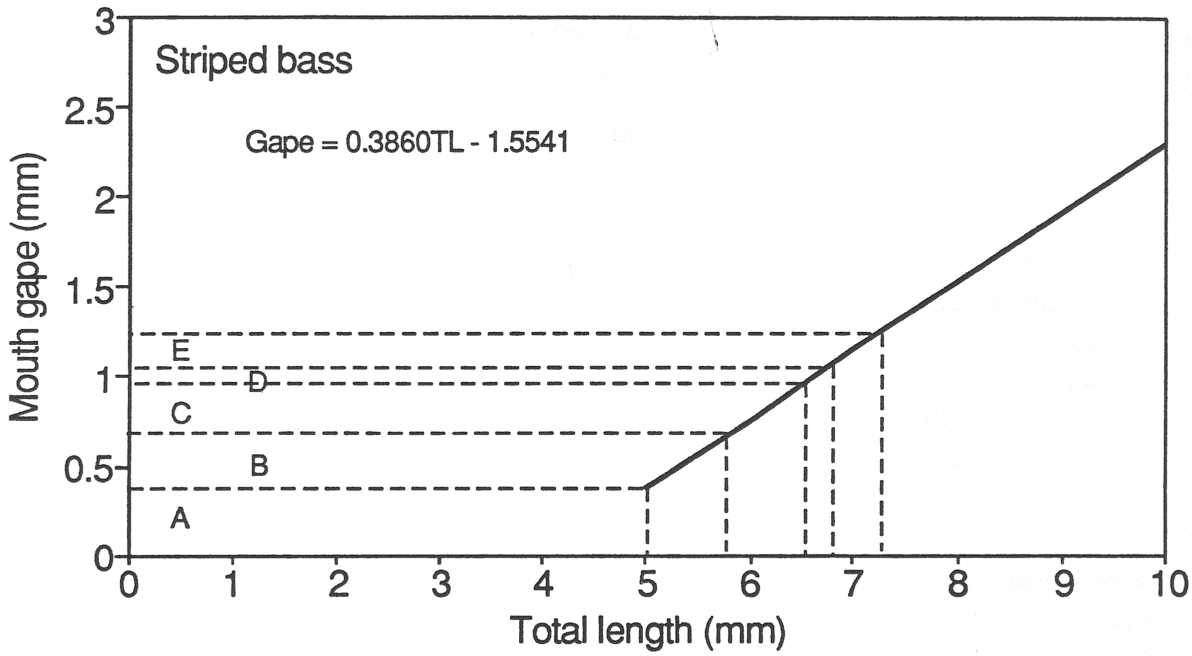

Figure 18. Relationship of 1) mouth gape size (mm) to total length (mm) of larval striped bass, and 2) possible zooplankton prey items to total fish length.

Food group A = cladoceran juveniles, calanoid and harpacticoid copepods, copepodids, copepod and cladoceran eggs and nauplii, ostracods, biting midge larvae, *Aeolosoma*, *Dero*, *Stylaria*, rotifers, nematodes, bivalve larvae, Collembola, *Hydra*, freshwater polychaetes, mysid shrimp.

Food group B = those in group A plus *Bosmina*, *Daphnia*, Sididae, Chydorinae, cyclopoid copepods, chironomid and phantom midge larvae, gammarid eggs, gastropods, colonial rotifers, arachnids, snail eggs, Gerridae adults, Elmidae.

Food group C = food groups A and B plus phantom midge and chironomid pupae, bivalves, gammarids, chironomid adults, Peltodytes larvae, turbellarians, Gyrinidae larvae.

Food group D = groups A through C plus Dixidae adults and Dytiscidae larvae.

Food group E = no additional study area zooplankters.

Table 31. Relative contribution (% by enumeration) of prey consumed by larval striped bass in the lower Roanoke River, North Carolina, 1984-1991. Period (.) = not observed in striped bass stomachs.

	Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
1	Clad. - Bosmina	.	78.39	86.49	.	80.73	.	.	36.17
2	Copepodids	.	16.13	6.69	.	11.01	.	.	8.51
3	Copepoda-egg mass	.	0.80	.	.	.	.	.	.
4	Ostracoda	.	0.20	1.14	.	0.92	.	.	2.13
5	Clad.-other (incl. Daphnia)	.	3.19	2.15	.	5.05	.	.	10.64
6	Detritus	.	0.08	0.25	.	0.46	.	.	6.38
7	Unidentified	.	0.48	0.25	.	0.46	.	.	2.13
8	Copepoda-nauplius	.	.	.	.	.	.	.	4.26
9,26	Dipt.-b.midge&chir.lar/pup.	.	0.12	2.90	.	0.46	.	.	4.26
10	Rotifer-single&colonial	.	0.08	.	.	.	.	.	.
11	Clad.-unid. egg	.	0.16	.	.	0.46	.	.	.
12	Bivalvia-larvae	.	.	.	.	0.46	.	.	.
13	Eph.-mayfly nymphs	.	.	.	.	.	.	.	.
14	Nematoda	.	.	.	.	.	.	.	.
15,27	Amphipoda - Gammarids	.	.	.	.	.	.	.	.
16	Arachnida	.	.	.	.	.	.	.	.
17	Hymenoptera-diving wasp	.	.	.	.	.	.	.	.
18	Oligo.-Aeol,Dero,Stylaria	.	.	.	.	.	.	.	.
19	Bivalvia	.	.	.	.	.	.	.	25.53
20	Tubellaria	.	.	.	.	.	.	.	.
21	Spongillafly larvae&adults	.	.	.	.	.	.	.	.
22	Bryozoans	.	.	.	.	.	.	.	.
23	Fish	.	0.12	.	.	.	.	.	.
24	Diptera adults-mosq.,chir., Dixidae, phant. midge,other	.	.	.	.	.	.	.	.
25	Copepoda-Cal.,Cyclo.,Har.	.	0.24	.	.	.	.	.	.
	Total prey items		2504	792	.	218	0	0	47
	Total fish examined	0	1676	4557	0	2213	21	1	921
	Total fish with food (%)	.	49	10	.	6	0	0	3

Table 32. Relative contribution (% by enumeration) of prey consumed by larval striped bass in Batchelor Bay, North Carolina, 1984-1991. Period (.) = not observed in striped bass stomachs.

	Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
1	Clad. - Bosmina	.	21.12	37.00	.	47.14	100	50	19.05
2	Copepodids	.	71.95	45.35	.	26.43	.	50	14.29
3	Copepoda-egg mass	.	.	11.20	.	2.20	.	.	.
4	Ostracoda	.	.	0.38	.	.	.	.	4.76
5	Clad.-other (incl. Daphnia)	100	2.97	1.90	.	3.08	.	.	.
6	Detritus	.	.	0.19	.	.	.	.	.
7	Unidentified	.	1.98	1.14	.	.	.	.	14.29
8	Copepoda-nauplius	.	.	2.85	.	.	.	.	.
9,26	Dipt.-b.midge&chir.larv./pup	.	.	.	.	2.20	.	.	.
10	Rotifer-single&colonial	.	.	.	.	0.44	.	.	.
11	Clad.-unid. egg	.	.	.	.	.	.	.	.
12	Bivalvia-larvae	.	.	.	.	.	.	.	.
13	Eph.-mayfly nymphs	.	.	.	.	.	.	.	.
14	Nematoda	.	.	.	.	.	.	.	.
15,27	Amphipoda - Gammarids	.	0.33	.	.	18.06	.	.	.
16	Arachnida	.	.	.	.	.	.	.	.
17	Hymenoptera-diving wasp	.	.	.	.	.	.	.	.
18	Oligo.-Aeol,Dero,Stylaria	.	0.66	.	.	.	.	.	.
19	Bivalvia	.	0.33	.	.	0.44	.	.	14.29
20	Tubellaria	.	.	.	.	.	.	.	.
21	Spongillafly larvae&adults	.	.	.	.	.	.	.	.
22	Bryozoans	.	.	.	.	.	.	.	.
23	Fish	.	0.33	.	.	.	.	.	.
24	Diptera adults-mosq.,chir., Dixidae, phant. midge,other	.	.	.	.	.	.	.	.
25	Copepoda-Cal.,Cyclo.,Har.	.	0.33	.	.	.	.	.	33.33
	Total prey items	1	303	527		227	2	2	21
	Total fish examined	6	147	431	0	312	18	7	771
	Total fish with food (%)	17	59	45	.	38	6	29	2

Table 33. Relative contribution (% by enumeration) of prey consumed by larval striped bass in western Albemarle Sound, North Carolina, 1984-1991. Period (.) = not observed in striped bass stomachs.

	Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
1	Clad. - Bosmina	.	.	.	.	3.47	16.67	10.12	0.85
2	Copepodids	.	.	100	100	95.66	83.33	85.71	58.36
3	Copepoda-egg mass	.	.	.	.	.	.	.	.
4	Ostracoda	.	.	.	.	.	.	.	.
5	Clad.-other (incl. Daphnia)	.	.	.	.	.	.	3.57	0.28
6	Detritus	.	.	.	.	.	.	.	.
7	Unidentified	.	.	.	.	.	.	.	0.28
8	Copepoda-nauplius	.	.	.	.	.	.	.	.
9,26	Dipt.-b.midge&chir.larv/pup	.	.	.	.	.	.	.	.
10	Rotifer-single&colonial	.	.	.	.	.	.	0.60	0.85
11	Clad.-unid. egg	.	.	.	.	.	.	.	.
12	Bivalvia-larvae	.	.	.	.	.	.	.	.
13	Eph.-mayfly nymphs	.	.	.	.	.	.	.	.
14	Nematoda	.	.	.	.	.	.	.	.
15,27	Amphipoda - Gammarids	.	.	.	.	0.87	.	.	.
16	Arachnida	.	.	.	.	.	.	.	.
17	Hymenoptera-diving wasp	.	.	.	.	.	.	.	.
18	Oligo.-Aeol,Dero,Stylaria	.	.	.	.	.	.	.	.
19	Bivalvia	.	.	.	.	.	.	.	.
20	Tubellaria	.	.	.	.	.	.	.	.
21	Spongillafly larvae&adults	.	.	.	.	.	.	.	.
22	Bryozoans	.	.	.	.	.	.	.	.
23	Fish	.	.	.	.	.	.	.	.
24	Diptera adults-mosq.,chir., Dixidae, phant. midge,other	.	.	.	.	.	.	.	.
25	Copepoda-Cal.,Cyclo.,Har.	.	.	.	.	.	.	.	39.38
	Total prey items	.	.	4	1	576	6	168	353
	Total fish examined	0	0	3	1	3	3	15	194
	Total fish with food (%)	.	.	100	100	53	67	73	47

Table 34. Relative contribution (% by enumeration) of prey consumed by undifferentiated *Morone* larvae in the lower Roanoke River, North Carolina, 1984-1991. Period (.) = not observed in larval stomachs.

Taxonomic group		1984	1985	1986	1987	1988	1989	1990	1991
1	Clad. - Bosmina	.	59.00	74.47	.	18.19	.	.	.
2	Copepodids	.	37.10	6.98	.	.	.	.	.
3	Copepoda-egg mass	.	1.45	.	.	.	.	.	.
4	Ostracoda	.	0.39	.	.	.	.	.	.
5	Clad.-other (incl. Daphnia)	100	1.16	.	.	81.81	.	.	..
6	Detritus	.	0.05	.	.	.	.	.	.
7	Unidentified	.	0.43	2.33	.	.	.	.	.
8	Copepoda-nauplius	.	.	.	.	.	.	.	.
9,26	Dipt.-b.midge&chir.larv./pup.		0.10	16.28	.	.	.	.	..
10	Rotifer-single&colonial	.	.	.	.	.	.	.	.
11	Clad.-unid. egg	.	.	.	.	.	.	.	.
12	Bivalvia-larvae	.	.	.	.	.	.	.	.
13	Eph.-mayfly nymphs	.	.	.	.	.	.	.	.
14	Nematoda	.	.	.	.	.	.	.	.
15,27	Amphipoda - Gammarids	.	.	.	.	.	.	.	.
16	Arachnida	.	.	.	.	.	.	.	.
17	Hymenoptera-diving wasp	.	.	.	.	.	.	.	.
18	Oligo.-Aeol,Dero,Stylaria	.	.	.	.	.	.	.	.
19	Bivalvia	.	.	.	.	.	.	.	.
20	Tubellaria	.	.	.	.	.	.	.	.
21	Spongillafly larvae&adults	.	.	.	.	.	.	.	.
22	Bryozoans	.	.	.	.	.	.	.	.
23	Fish	.	0.01	.	.	.	.	.	.
24	Diptera adults-mosq.,chir., Dixidae, phant. midge,other	.	.	.	.	.	.	.	.
25	Copepoda-Cal.,Cyclo.,Har.	.	0.24	.	.	.	.	.	.
Total prey items		2	2073	43	.	11	.	.	.
Total fish examined		45	1117	27	0	4	0	0	0
Total fish with food (%)		2	53	56	.	75	.	.	.

consumed mostly copepodids, but *Daphnia* and amphipods were important in some years (Table 35). Copepodids were the major prey for undifferentiated *Morone* larvae in western Albemarle Sound (Table 36).

White perch larvae exhibited a wider variety of prey items in 1988. Although *Bosmina* was the primary food item (35%) for white perch larvae in the River, both cladoceran and copepod eggs represented about 35% of all items consumed (Table 37). *Bosmina* and copepodids comprised about 67% of the larval white perch diet in Batchelor Bay (Table 38), and copepodids alone represented 97% of the diet in western Albemarle Sound (Table 39).

An electivity index was used to determine whether larval striped bass, white perch, and *Morone* sp. were consuming prey taxa in a proportion similar to that observed in the zooplankton community, or in a proportion suggesting selective feeding. Lechowicz (1982) described and compared seven index algorithms and determined that none of them effectively describe feeding habits under all possible conditions. We compared three of the seven indexs: Ivlev's electivity index, Ivlev's forage ratio, and Strauss linear index (Ivlev 1961, Strauss 1979). We selected the linear index because it has the following properties: 1) the value ranges from -1 (indicating avoidance or inaccessibility), to +1 (indicating preference); 2) the expected value for random feeding is zero; and 3) extreme values occur only when the prey item is rare but consumed almost exclusively, or is very abundant but rarely consumed. The data were subsetted to include only those stations and dates for which larval fish had consumed a prey item. Strauss' Linear Index was then calculated for each zooplankton taxa by date and station, and a single value was obtained for each station by averaging all index values for that particular zooplankter. The index value is simply the unweighted difference in proportions

$$L = r_i - p_i,$$

where r_i is the relative abundance of prey item i in the gut, and p_i is the relative proportion of prey item i in the zooplankton.

The linear index values plotted by station suggest that larval striped bass prefer *Bosmina* in the Roanoke Delta (Stations 5-12) and copepodids in Batchelor Bay and western Sound (Figure 19). Adult copepods and *Daphnia* were not consumed by striped bass larvae at a rate consumate with their relative contribution to the zooplankton community. Ostracods appeared to be consumed at random. Undifferentiated *Morone* larvae exhibited index values similar in pattern to larval striped bass.

White perch had negative index values for *Bosmina*, *Daphnia*, and adult copepods (Figure 19). Since white perch larvae are smaller than larval striped bass, these negative index values may indicate that the prey was too large for the larva (i.e., mouth gape). Mouth part differences between striped bass and white perch need to be assessed before firm conclusions can be drawn.

Table 35. Relative contribution (% by enumeration) of prey consumed by undifferentiated *Morone* larvae in Batchelor Bay, North Carolina, 1984-1991. Period (.) = not observed in larval stomachs.

Taxonomic group		1984	1985	1986	1987	1988	1989	1990	1991
1	Clad. - Bosmina	.	17.17	10.20	.	.	.	.	.
2	Copepodids	75.00	76.32	87.76	.	13.33	.	.	.
3	Copepoda-egg mass	.	3.19	.	.	.	.	.	.
4	Ostracoda	.	.	.	.	.	.	.	.
5	Clad.-other (incl. Daphnia)	25.00	1.80	2.04	.	.	66.67	.	.
6	Detritus	.	.	.	.	.	.	.	.
7	Unidentified	.	0.70	.	.	.	33.33	.	.
8	Copepoda-nauplius	.	.	.	.	.	.	.	.
9,26	Dipt.-b.midge&chir.larv./pup	.	0.14	.	.	.	.	.	.
10	Rotifer-single&colonial	.	.	.	.	.	.	.	.
11	Clad.-unid. egg	.	.	.	.	.	.	.	.
12	Bivalvia-larvae	.	.	.	.	.	.	.	.
13	Eph.-mayfly nymphs	.	.	.	.	.	.	.	.
14	Nematoda	.	.	.	.	.	.	.	.
15,27	Amphipoda - Gammarids	.	0.14	.	.	80.00	.	.	.
16	Arachnida	.	.	.	.	.	.	.	.
17	Hymenoptera-diving wasp	.	.	.	.	.	.	.	.
18	Oligo.-Aeol,Dero,Stylaria	.	.	.	.	.	.	.	.
19	Bivalvia	.	.	.	.	6.67	.	.	.
20	Tubellaria	.	.	.	.	.	.	.	.
21	Spongillafly larvae&adults	.	.	.	.	.	.	.	.
22	Bryozoans	.	.	.	.	.	.	.	.
23	Fish	.	.	.	.	.	.	.	.
24	Diptera adults-mosq.,chir., Dixidae, phant. midge,other	.	.	.	.	.	.	.	.
25	Copepoda-Cal.,Cyclo.,Har.	.	0.55	.	.	.	.	.	.
Total prey items		4	722	49	.	15	3	.	.
Total fish examined		17	226	11	0	5	2	0	0
Total fish with food (%)		12	84	82	.	80	50	.	.

Table 36. Relative contribution (% by enumeration) of prey consumed by undifferentiated *Morone* larvae in western Albemarle Sound, North Carolina, 1984-1991. Period (.) = not observed in larval stomachs.

	Taxonomic group	1984	1985	1986	1987	1988	1989	1990	1991
1	Clad. - Bosmina	.	.	.	.	0.60	12.86	.	.
2	Copepodids	.	.	100	100	95.42	81.43	100	84.36
3	Copepoda-egg mass	.	.	.	.	.	.	.	.
4	Ostracoda	.	.	.	.	.	.	.	.
5	Clad.-other (incl. Daphnia)	.	.	.	.	0.73	1.43	.	.
6	Detritus	.	.	.	.	.	0.09	.	.
7	Unidentified	.	.	.	.	0.14	.	.	0.22
8	Copepoda-nauplius	.	.	.	.	.	.	.	.
9,26	Dipt.-b.midge&chir.larv./pup.	.	.	.	.	0.41	1.43	.	.
10	Rotifer-single&colonial	.	.	.	.	.	.	.	.
11	Clad.-unid. egg	.	.	.	.	.	.	.	.
12	Bivalvia-larvae	.	.	.	.	.	.	.	.
13	Eph.-mayfly nymphs	.	.	.	.	.	.	.	.
14	Nematoda	.	.	.	.	.	.	.	.
15,27	Amphipoda - Gammarids	.	.	.	.	2.61	.	.	.
16	Arachnida	.	.	.	.	.	.	.	.
17	Hymenoptera-diving wasp	.	.	.	.	.	.	.	.
18	Oligo.-Aeol,Dero,Stylaria	.	.	.	.	.	.	.	.
19	Bivalvia	.	.	.	.	.	.	.	.
20	Tubellaria	.	.	.	.	.	.	.	.
21	Spongillafly larvae&adults	.	.	.	.	.	.	.	.
22	Bryozoans	.	.	.	.	.	.	.	.
23	Fish	.	.	.	.	.	.	.	.
24	Diptera adults-mosq.,chir., Dixidae, phant. midge,other	.	.	.	.	.	.	.	.
25	Copepoda-Cal.,Cyclo.,Har.	.	.	.	.	.	2.86	.	15.42
	Total prey items	.	.	1	8	2183	70	108	454
	Total fish examined	2	0	1	8	101	35	5	46
	Total fish with food (%)	0	.	100	38	91	40	100	85

Table 37. Relative contribution (% by enumeration) of prey consumed by white perch larvae in the lower Roanoke River, North Carolina, 1984-1991. Period (.) = not observed in larval stomachs.

Taxonomic group		1984	1985	1986	1987	1988	1989	1990	1991
1	Clad. - Bosmina	.	.	.	.	35.83	.	.	14.29
2	Copepodids	.	.	.	.	7.08	.	.	14.29
3	Copepoda-egg mass	.	.	.	.	6.25	.	.	.
4	Ostracoda	.	.	.	.	0.42	.	.	.
5	Clad.-other (incl. Daphnia)	.	.	.	.	2.08	.	.	14.29
6	Detritus	.	.	.	.	5.0	.	.	42.86
7	Unidentified	.	.	.	.	11.25	.	.	.
8	Copepoda-nauplius	.	.	.	.	.	.	.	.
9,26	Dipt.-b.midge&chir.larv./pup.	.	.	.	.	0.83	.	.	.
10	Rotifer-single&colonial	.	.	.	.	1.25	.	.	14.29
11	Clad.-unid. egg	.	.	.	.	29.17	.	.	.
12	Bivalvia-larvae	.	.	.	.	.	.	.	.
13	Eph.-mayfly nymphs	.	.	.	.	0.83	.	.	.
14	Nematoda	.	.	.	.	.	.	.	.
15,27	Amphipoda - Gammarids	.	.	.	.	.	.	.	.
16	Arachnida	.	.	.	.	.	.	.	.
17	Hymenoptera-diving wasp	.	.	.	.	.	.	.	.
18	Oligo.-Aeol,Dero,Stylaria	.	.	.	.	.	.	.	.
19	Bivalvia	.	.	.	.	.	.	.	.
20	Tubellaria	.	.	.	.	.	.	.	.
21	Spongillafly larvae&adults	.	.	.	.	.	.	.	.
22	Bryozoans	.	.	.	.	.	.	.	.
23	Fish	.	.	.	.	.	.	.	.
24	Diptera adults-mosq.,chir., Dixidae, phant. midge,other	.	.	.	.	.	.	.	.
25	Copepoda-Cal.,Cyclo.,Har.	.	.	.	.	.	.	.	.
Total prey items		.	.	.	.	240	.	.	7
Total fish examined		.	.	.	.	199	.	.	28
Total fish with food (%)		.	.	.	.	43	.	.	21

Table 38. Relative contribution (% by enumeration) of prey consumed by white perch larvae in Batchelor Bay, North Carolina, 1984-1991. Period (.) = not observed in larval stomachs.

Taxonomic group		1984	1985	1986	1987	1988	1989	1990	1991
1	Clad. - Bosmina	.	.	.	.	21.05	.	.	.
2	Copepodids	.	.	.	.	47.37	.	.	.
3	Copepoda-egg mass	.	.	.	.	.	.	.	.
4	Ostracoda	.	.	.	.	.	.	.	.
5	Clad.-other (incl. Daphnia)	.	.	.	.	5.26	.	.	.
6	Detritus	.	.	.	.	5.26	.	.	.
7	Unidentified	.	.	.	.	10.53	.	.	.
8	Copepoda-nauplius	.	.	.	.	.	.	.	.
9,26	Dipt.-b.midge&chir.larv./pup	.	.	.	.	.	.	.	.
10	Rotifer-single&colonial	.	.	.	.	5.26	.	.	.
11	Clad.-unid. egg	.	.	.	.	.	.	.	.
12	Bivalvia-larvae	.	.	.	.	.	.	.	.
13	Eph.-mayfly nymphs	.	.	.	.	.	.	.	.
14	Nematoda	.	.	.	.	.	.	.	.
15,27	Amphipoda - Gammarids	.	.	.	.	.	.	.	.
16	Arachnida	.	.	.	.	.	.	.	.
17	Hymenoptera-diving wasp	.	.	.	.	.	.	.	.
18	Oligo.-Aeol,Dero,Stylaria	.	.	.	.	.	.	.	.
19	Bivalvia	.	.	.	.	5.26	.	.	.
20	Tubellaria	.	.	.	.	.	.	.	.
21	Spongillafly larvae&adults	.	.	.	.	.	.	.	.
22	Bryozoans	.	.	.	.	.	.	.	.
23	Fish	.	.	.	.	.	.	.	.
24	Diptera adults-mosq.,chir., Dixidae, phant. midge,other	.	.	.	.	.	.	.	.
25	Copepoda-Cal.,Cyclo.,Har.	.	.	.	.	.	.	.	.
Total prey items		.	.	.	.	19	.	.	0
Total fish examined		.	.	.	.	31	.	.	1
Total fish with food (%)		.	.	.	.	52	.	.	0

Table 39. Relative contribution (% by enumeration) of prey consumed by white perch larvae in western Albemarle Sound, North Carolina, 1984-1991. Period (.) = not observed in larval stomachs.

Taxonomic group		1984	1985	1986	1987	1988	1989	1990	1991
1	Clad. - Bosmina	.	.	.	.	.	.	.	.
2	Copepodids	.	.	.	.	97.50	.	.	.
3	Copepoda-egg mass	.	.	.	.	.	.	.	.
4	Ostracoda	.	.	.	.	.	.	.	.
5	Clad.-other (incl. Daphnia)	.	.	.	.	.	.	.	.
6	Detritus	.	.	.	.	.	.	.	.
7	Unidentified	.	.	.	.	0.25	.	.	.
8	Copepoda-nauplius	.	.	.	.	2.00	.	.	.
9,26	Dipt.-b.midge&chir.larv./pup	.	.	.	.	0.25	.	.	.
10	Rotifer-single&colonial	.	.	.	.	.	.	.	.
11	Clad.-unid. egg	.	.	.	.	.	.	.	.
12	Bivalvia-larvae	.	.	.	.	.	.	.	.
13	Eph.-mayfly nymphs	.	.	.	.	.	.	.	.
14	Nematoda	.	.	.	.	.	.	.	.
15,27	Amphipoda - Gammarids	.	.	.	.	.	.	.	.
16	Arachnida	.	.	.	.	.	.	.	.
17	Hymenoptera-diving wasp	.	.	.	.	.	.	.	.
18	Oligo.-Aeol,Dero,Stylaria	.	.	.	.	.	.	.	.
19	Bivalvia	.	.	.	.	.	.	.	.
20	Tubellaria	.	.	.	.	.	.	.	.
21	Spongillafly larvae&adults	.	.	.	.	.	.	.	.
22	Bryozoans	.	.	.	.	.	.	.	.
23	Fish	.	.	.	.	.	.	.	.
24	Diptera adults-mosq.,chir., Dixidae, phant. midge,other	.	.	.	.	.	.	.	.
25	Copepoda-Cal.,Cyclo.,Har.	.	.	.	.	.	.	.	.
Total prey items		.	.	.	.	401	.	.	0
Total fish examined		.	.	.	.	10	.	.	1
Total fish with food (%)		.	.	.	.	80	.	.	0

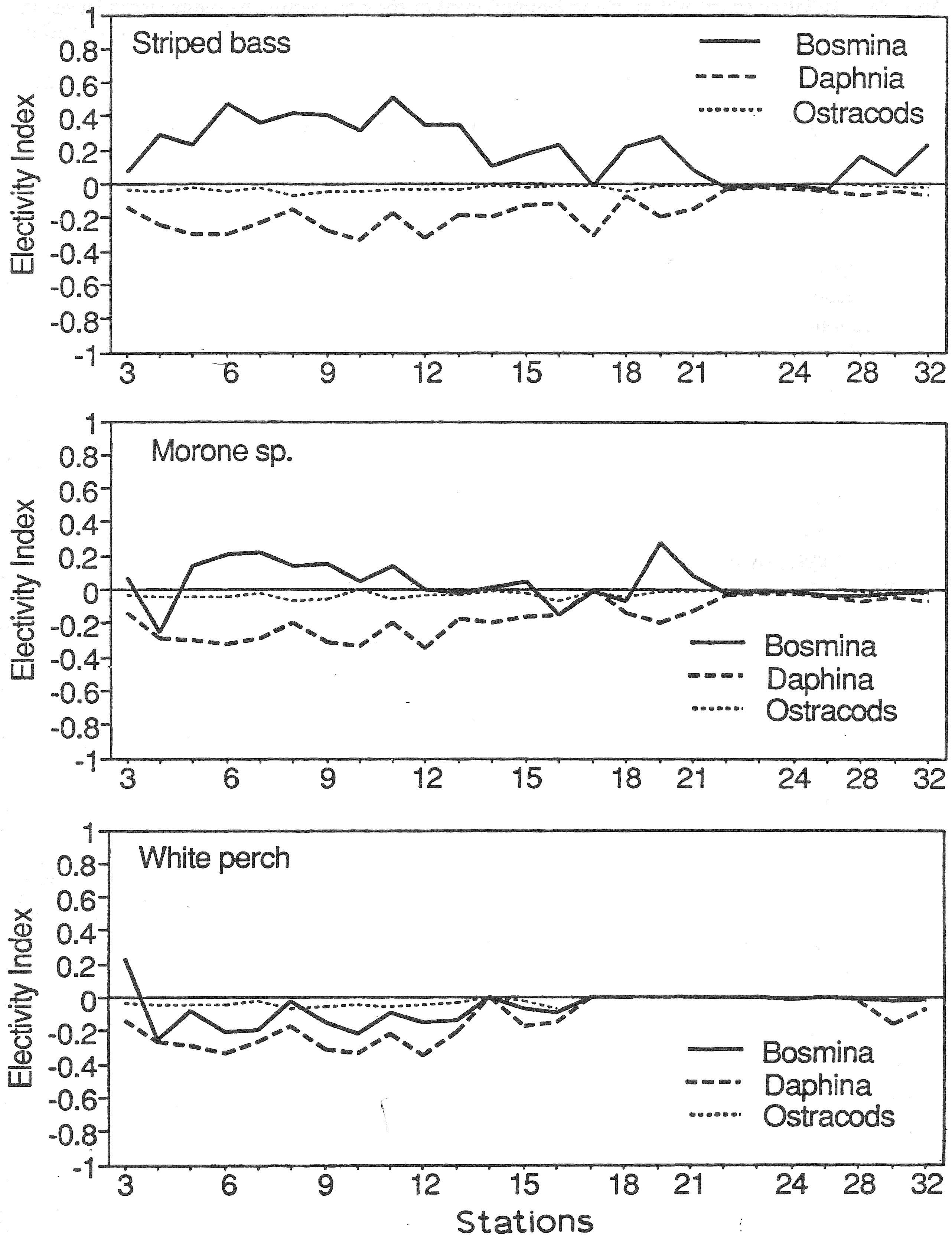

Figure 19. Strauss' linear index of electivity calculated for larval striped bass, white perch, and undifferentiated *Morone* larvae and six zooplankton taxa. Positive value indicates preference; negative value indicates avoidance or inaccessibility.

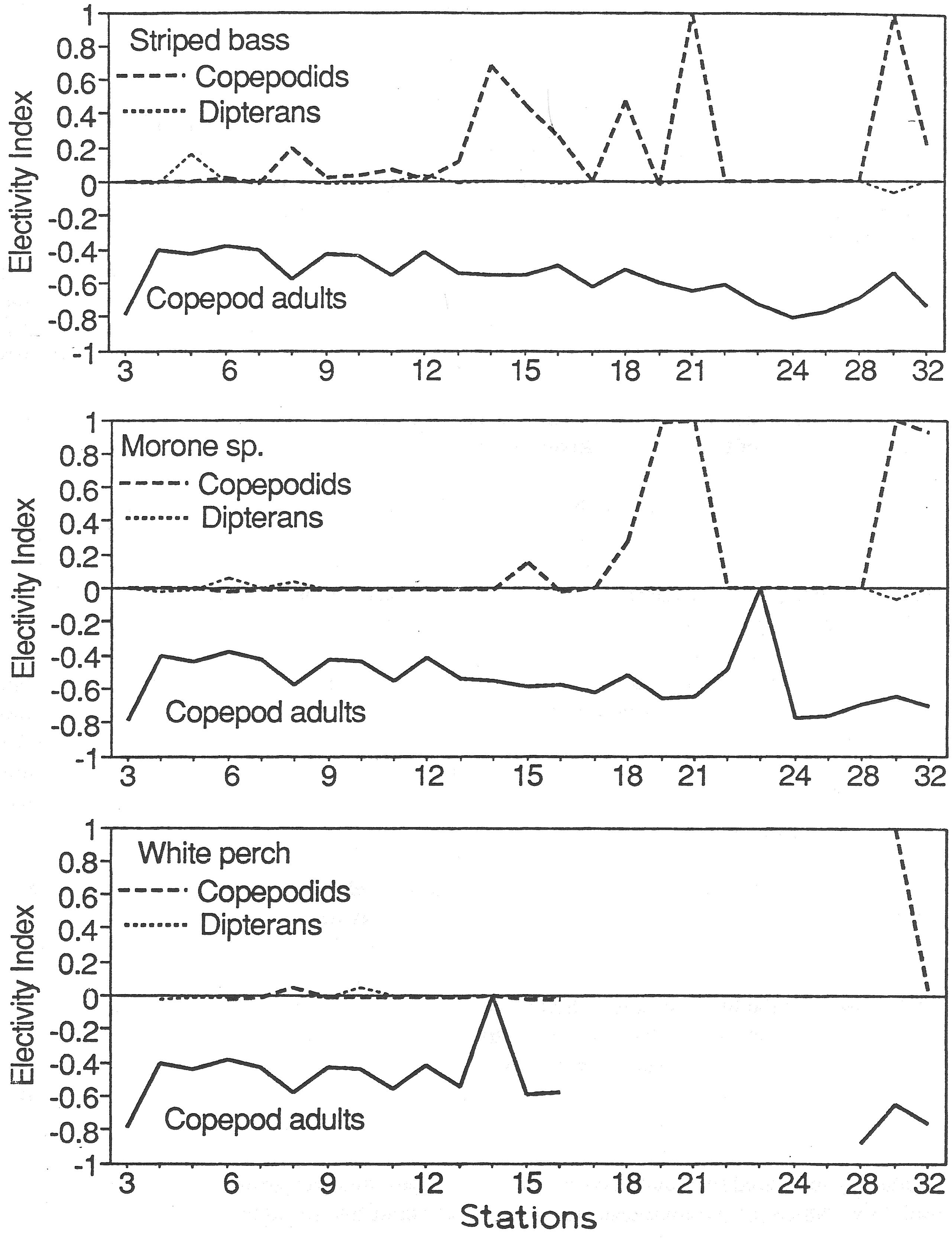

Figure 19. (continued).

Discussion

The composition of the phytoplankton in the lower Roanoke resembles that from a lake more closely than that from an estuarine environment, which is not surprising in light of the low salinity in the area. This freshwater habitat is better suited for species of green algae and diatoms that are common in lakes and ponds than for the dinoflagellates and chrysophytes that have been found to be predominant in higher salinity estuaries of the Albemarle-Pamlico Sound system farther to the south. For example, in the Pamlico River Estuary in 1984 about 80% of the phytoplankton biomass downriver (salinity 10-20 ppt) consisted of chrysophytes and dinoflagellates at this time of year. Upriver, on the other hand, in 0-2 ppt salinity water, the Pamlico assemblage closely resembled that in the Roanoke (Stanley and Daniel 1985). Similarly, to the north, in the lower James River, where salinity is also high, Marshall (1967) found that no green algae were common during the spring and early summer. Likewise, Carpenter (1971) found green algae to be less predominant than dinoflagellates in the lower end (5-25 ppt salinity) of the Cape Fear River estuary.

In 1984 chlorophyll *a* and phytoplankton biomass were relatively low in the Roanoke, and also in the nearby Pamlico River Estuary where data were collected on a bi-weekly basis throughout the year. In May and June phytoplankton cell density and biomass were only slightly higher in the upper (freshwater) portion of the Pamlico than in the Roanoke (Stanley and Daniel 1985). However, it is obvious from examination of data for the Pamlico from previous years that the algal biomass there is normally much higher. It appears that unusually high river flow in early June 1984 resulted in washout of most of the Pamlico phytoplankton (Stanley and Daniel 1985). Similarly, the unusually high flow in the Roanoke probably caused a washout of the phytoplankton in 1984 also. This hypothesis is supported by the fact that in 1985 both Roanoke and Pamlico flows were lower (for the same May-June period), and indeed phytoplankton biomass was higher than in 1984, both in the Roanoke and in the Pamlico (D.W. Stanley, unpublished data).

There was no significant correlation between Roanoke chlorophyll *a* concentrations and phytoplankton biomass, which is not surprising for a system like the lower Roanoke. A regression of chlorophyll against phytoplankton biomass yielded a r^2 of only 0.05, indicating no relationship between the two parameters. Two possible reasons for this come to mind. First, it is well known that the biomass:chlorophyll ratio varies widely (7-fold or more) in phytoplankton, depending on the species composition and nutritional status of the cells (Valiella 1984). Second, the chlorophyll *a* levels measured for the Roanoke were near the lower limit of detection by the method used in our laboratory. In any case, the biomass:chlorophyll ratio for the Roanoke averaged 51, which is close to the value of 50 often reported as an average (e.g., Valiella 1984). Both parameters are useful: chlorophyll *a* for comparison to other systems because it is commonly measured in aquatic ecosystems of all types, and wet weight biomass because it a useful for addressing questions concerning trophic structure and functioning.

Most of the algae are small species that should be usable as food for grazing zooplankton in the river. Blue-green algae, which are usually classified as undesirable food for zooplankters, were not present in significant quantities in the Roanoke. There were no species found from other taxonomic groups that have been reported to be toxic or otherwise undesirable to zooplankters. Instead, most of the biomass consisted of species that were individual cells less than 20 µm in diameter, when calculated as spherical equivalents. Actual maximum dimensions were mostly less than 75 µm.

A comparison of zooplankton and phytoplankton biomass in the Roanoke suggests that zooplankton production is not limited by low phytoplankton production. McCauley and Kalff (1981) used data gathered from 13 different lakes to develop an empirical relationship between the two. In this intra-lake comparison they found that as phytoplankton biomass increases, so does zooplankton biomass, but at a slower rate. They interpreted this to indicate that as phytoplankton biomass increases, nannoplankton production relative to total phytoplankton production decreases (i.e., the average algae size increases). It is known that nannoplankton (algae <20 µm diameter) represent the principal food source for crustacean zooplankters. Figure 20 is a plot, similar to that presented for the various lakes by McCauley and Kalff, of log phytoplankton biomass vs. log zooplankton biomass for the Roanoke samples taken in 1984 and 1985. Like the McCauley and Kalff plot it shows that within a given system there is considerable variability in the ratio from sample to sample. In fact, for the Roanoke, as well as for any given individual lake in their plot, the relationship described above is not apparent. It is only when different lakes spanning a wide range of phytoplankton productivity are compared that the pattern becomes obvious. The Roanoke results are interesting, however, because most the phytoplankton biomass values fall within the lake data range, while the zooplankton biomass was much lower (average about 10 µg/L) than in the lakes (100-1000 µg/L). Thus, in the Roanoke the zooplankton:phytoplankton biomass ratio was very much lower (0.01-0.001) than in the lakes surveyed (average about 1.0). The ratio was low not because of unusually low phytoplankton biomass, but because of such low zooplankton biomass. Our conclusion is that zooplankton production in the Roanoke is probably not limited by phytoplankton production.

Since zooplankton should not be phytoplankton limited, then environmental factors must play a role in maintaining low zooplankton abundance. Results of the study indicate that daily river flow, as well as seasonal flow patterns, can change the zooplankton communities of the Roanoke/western Albemarle Sound system. Water temperature, which can be altered by cool reservoir releases upstream, is a major factor in zooplankton abundance because it affects the rate of reproduction. Salinity is normally less than 1 ppt in western Albemarle Sound, but under low flow conditions brackish water can move upstream through the delta area and alter the zooplankton communities. Prevailing winds in Albemarle Sound also could change the zooplankton community structure and assist brackish water intrusion. Until the USGS completes and validates the mathematical flow model for the study area, the relationship of river flow and its effects on environmental conditions and, therefore, zooplankton distribution and composition, will be difficult to interpret.

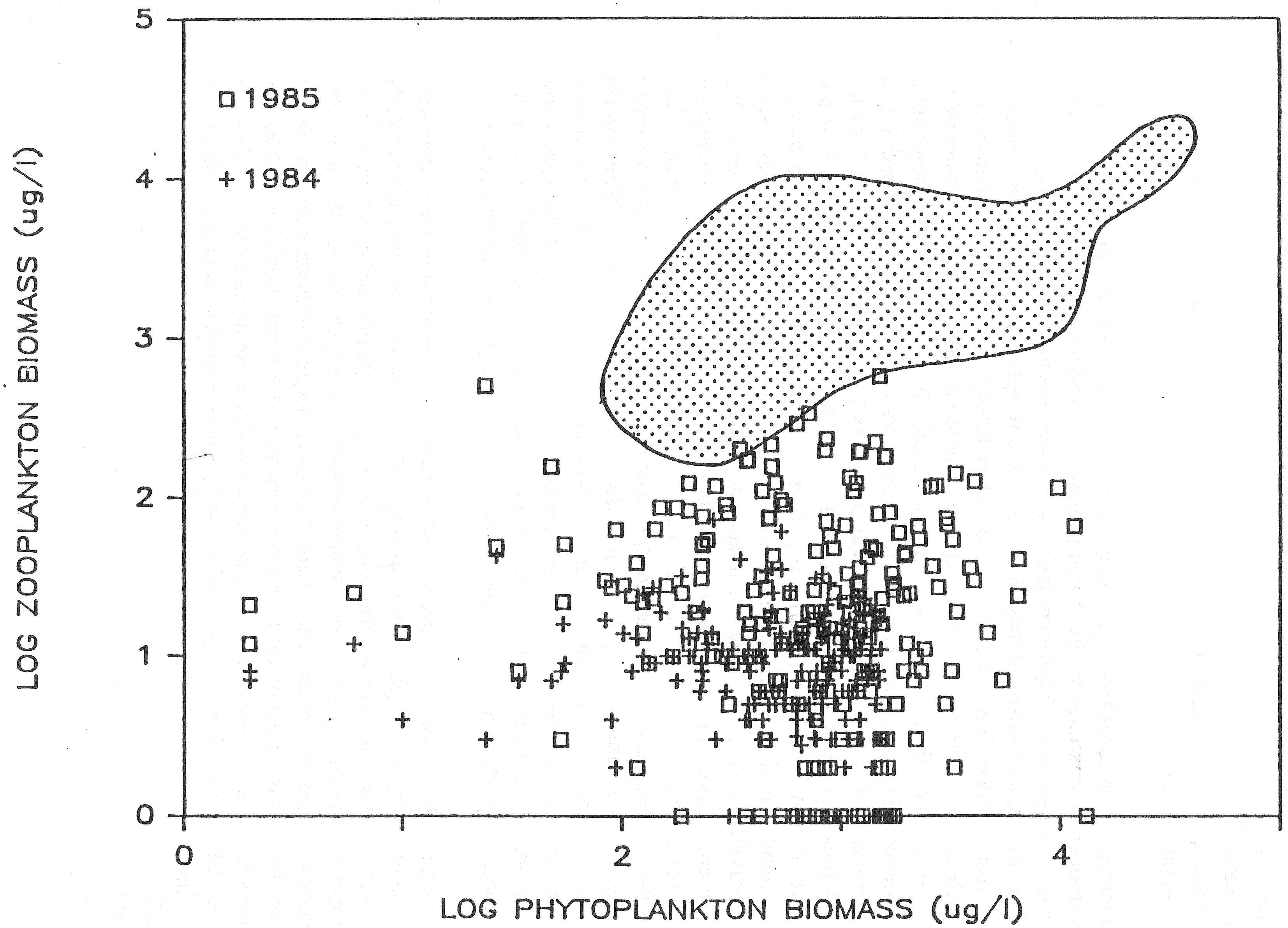

Figure 20. Log phytoplankton biomass vs. log zooplankton biomass for Roanoke study area samples in 1984 and 1985. Shaded area indicates range of values compiled for 13 lakes by McCauley and Kalff (1981).

Zooplankton is the major food source for larval striped bass in the Roanoke River and western Albemarle Sound. Studies in other river systems indicate that changes in the zooplankton food supply during the critical early life stages directly affect striped bass recruitment (Boynton et al. 1981; Eldrige et al. 1981a, 1981b; Kernehan et al. 1981; Mihursky et al. 1981; Martin et al. 1985; Rozengurt and Herz 1985; Stevens et al. 1985; Setzler-Hamilton et al. 1987). River flow and water temperature are two major environmental factors directly affecting the zooplankton food supply in other systems.

We have documented the patchy distribution of zooplankton abundance in the critical habitat areas for larval striped bass in the Roanoke system; since larval transport is directly related to instream flow near the spawning grounds, the speed downstream transport combined with water temperature will determine the approximate location at which feeding is first initiated. A mismatch in time and/or space of the zooplankton food supply and fully functional larvae ready to initiate feeding is referred to as the "Match/Mismatch" hypothesis and is believed to be a primary factor in recruitment of young striped bass to the forming year class. Both river flow and water temperature are thought to be major factors controlling the match/mismatch phenomenon.

We conclude that one factor influencing the number of Roanoke striped bass larvae recruiting successfully to the forming year class in Albemarle Sound is the match/mismatch phenomenon driven by seasonal and daily patterns in instream flow. Seasonally moderate instream flow patterns position the larvae lower in the River and Delta where zooplankton densities are greatest, and then gradually carry them to the western Sound nurseries. Low flows cannot provide the current needed by larvae to move them into Batchelor Bay and the Sound in a timely fashion, and high flows flush both zooplankton and larvae out of the Delta before feeding is initiated. The low zooplankton concentrations observed in this system do not mean that successful year classes are not possible: in years of high larval production, more young will survive regardless of food supply in the river. However, larval survival would be enhanced if habitat conditions, such as an adequate food supply, were optimal.

The river flow-striped bass recruitment relationship is not unique to this watershed. Researchers have documented the phenomenon for a number of east coast populations: Chesapeake Bay (Ulanowicz and Polgar 1980; Uphoff 1989, 1992), the Santee-Cooper River in South Carolina (Bulak, personal communication), the Ogeechee River (Bettross 1991), and the Savannah River in Georgia (Van den Avyle et al. 1990). On the west coast, similar flow/recruitment relationships have been documented for the San Francisco/Delta ecosystem and Sacramento-San Joaquin system (Chadwick 1964; Turner and Chadwick 1972; Stevens 1977; Chadwick et al. 1977; Stevens 1980; Herrgesell et al. 1983; Rozengurt and Herz 1985; Stevens et al. 1985, 1987; California Fish and Game 1987, Kjelson and Brandes 1987). Similar river flow-recruitment relationships have been documented for American shad in the Connecticut River (Leggett 1980; Crecco and Savoy 1984, 1987), white perch in the Choptank River (Summers et al. 1990), and salmon in the San Francisco/Delta ecosystem (Fisher et al. 1991) and Sacramento-San Joaquin Estuary (Kjelson and Brandes 1987).

Striped bass larvae in the Roanoke system have a relatively low success rate in feeding compared to white perch in the same areas. Whether this phenomenon is true of other fish species in the watershed remains to be determined. Additional studies are underway to determine the feeding success of other larval fishes collected during this eight-year period.

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SECTION II

USE OF EMERGENT AQUATIC VEGETATION BY LARVAL FISHES IN THE ROANOKE RIVER, NORTH CAROLINA, 1987-1989

by

John E. Cooper and Roger A. Rulifson

INTRODUCTION

Vegetated areas within a river system are important to young fish as a refuge to escape predation (Werner et al. 1983) and can serve as a source of food when the presence of predators prevents foraging in the more energetically-profitable non-vegetated areas (Gilliam et al. 1987). Vegetated areas support a wide variety of zooplankters that are utilized for food by many larval fish (Doroshev 1970; Miller and Kramer 1971; Siefert 1972; Keast and Eadie 1985; Jackson and Schmitz 1987; Engel 1990). Studies of vegetated areas have focused primarily on submerged vegetation such as *Potamogeton* (pondweeds), *Chara* (muskgrasses), *Najas* (bushy pondweed) (Durocher et al. 1984; Wiley et al. 1984), *Hydrilla* (hydrilla), *Vallisneria* (wild celery), *Myriophyllum* (Eurasian watermilfoil), *Ceratophyllum* (coontail), *Heteranthera* (water stargrass), and *Nitella* (stonewort) (Killgore et al. 1989) and their relationship to adult fish populations. The loss of *Hydrilla* beds (Colle et al. 1989) indicated that adults of many fish species preferred physical structures (*Nyssa aquatica*, water tupelo; piers) to bare sand. Utilization of *Eleocharis* (spikerush), *Isoetes* (muskgrass and quillwort), and *Nelumbo* (American lotus) by juveniles of several species was found to be species-specific (Layzer and Clady 1989). Utilization by larval fish of *Scirpus* (bulrush)(Faber 1981) was primarily by those spawned in shallow areas. Larval fish were more abundant in riverine areas of little or no current where vegetation was common [*Potomogeton*, *Heteranthera*, *Myriophyllum*, and *Cladophora*,(Gerlach and Kahnle 1981), and the water willow *Justicus* (Floyd et al. 1984] than in areas of stronger current which lacked vegetation. Comparative distributions of larval fish stages in various types of vegetation, including *Nuphar*, was directly related to larval length in some species and inversely related in others (Conrow et al. 1990).

The shorelines of the lower Roanoke River and its distributaries support vegetated areas that are generally narrow in width but occasionally can extend over wide mud deposits near bends in the river. The only extensive vegetated areas are formed by water lilies. This study was undertaken to estimate the relative extent of water lily bed areas, to present a short-term "snapshot" of the potential prey-zooplankton that come from these areas, and to determine whether these areas are utilized by striped bass, *Morone saxatilis*, larvae.

Study site

The Roanoke River drains 25,035 km^2, 87% of which is located above Roanoke Rapids Dam, 134 river miles upstream from the study site. The remaining 13% of the watershed lies within the Coastal Plain Province and is bounded by bald cypress-tupelo gum swamp forest and small blackwater tributaries. The river was dammed for hydroelectric power at three sites (Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake) between 1950 and 1963. The rate of water discharge is measured at Roanoke Rapids Dam and varies considerably over time (Manooch and Rulifson 1989).

The Roanoke River delta is comprised of three main distributaries: the Cashie River, Middle and Eastmost Rivers, and the Roanoke. Bottom sediments of the Roanoke are an orange inorganic clay overlying medium to coarse sands fining upwards to fine sands, muds, or peats (Riggs et al. 1991). The vegetated areas have become established on mud deposits that have accumulated as a result of river impoundment. The shoreline edge in most areas is characterized by a steep dropoff (up to 20 m) except in areas of emergent vegetation.

Six stations were established in the most extensive water lily beds (Figure 1), three of which (7, 8, 12) coincided with a fixed station sampling design for larval fish established in 1984 (Rulifson et al. 1986). Station 7 (Roanoke River) was on the south shore adjacent to the Weyerhaeuser paper plant (175 m river width); Station 8 (Cashie River) was located 800 m upstream of the Highway 45 bridge in a wide embayment (240 m river width) on the north shore, and Station 12 (Roanoke River) was on the south shore 600 m downstream of the confluence of Canaby Creek and upstream of navigation marker R12 (160 m river width). Station 40 (Roanoke River) was on the south shore 3000 m upstream from the Highway 45 bridge (250 m river width), Station 41 (Eastmost River) on the north shore of a small island just downstream of the Highway 45 bridge (35 m river width), and Station 42 (Middle River) on the south side 2500 m upstream of the Highway 45 bridge in a wide, flat area where the river is 193 m in width. Station 10, another larval fish sampling station (Figure 1) was used for fish traps and was located on the south shore of the Roanoke River 500 m upstream of the Highway 45 bridge.

Rates of water discharge during our study ranged from a high of 35,000 cubic feet per second (cfs) to a low of 2500 cfs. Flood conditions existed in spring 1987 with a discharge rate of 35,000 cfs during the first sampling date in May which decreased to 18,000 cfs at the second sampling date in June. The spring of 1988 was a low flow period with average daily discharges never exceeding 10,000 cfs (7000 cfs at May samples, 2500 cfs at June samples). The spring of 1989 was a moderate period in terms of discharge (20,000 cfs at May samples, 9500 at June samples).

METHODS

Water Lily Beds

A survey of the largest *Nuphar* water lily beds in the three distributaries of the Roanoke River system was made in May (high water flow), 1987, and in April (low flow) in 1988. The size of each vegetated area was estimated using LORAN lines of position for reference. In 1989, water lily beds in each distributary were measured using fixed points and a tape measure during moderate flow conditions in August.

Pushnet Samples

Pushnet samples were collected alternately with river samples and were taken in the most extensive water lily beds in proximity to previously established larval fish sampling stations (Stations 7, 8, 12; Section I of this report). Other stations in small water lily beds (40, 41,

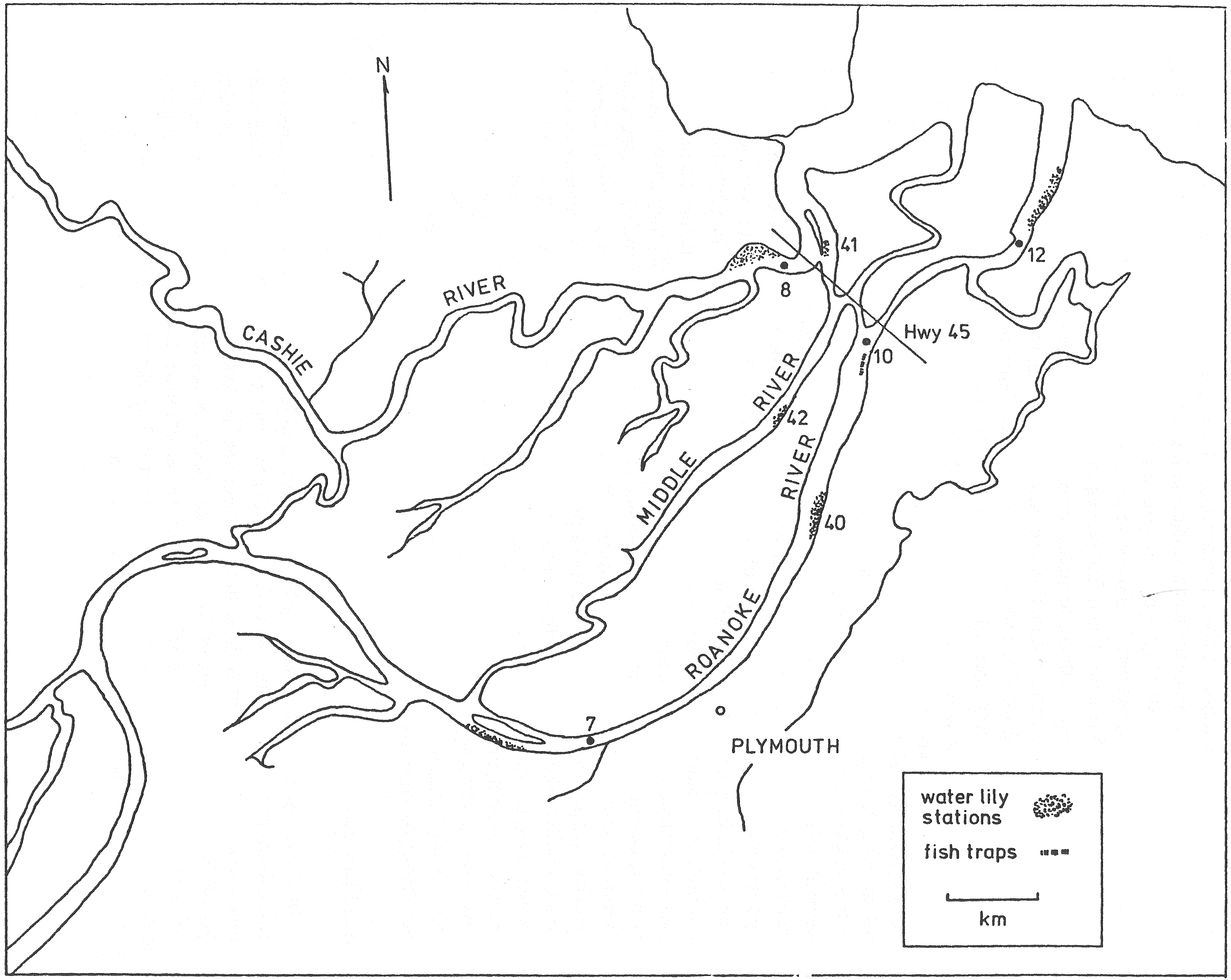

Figure 1. Water lily and fish trap sampling stations in the Roanoke River delta.

42; Table 1) were sampled opportunistically. On some occasions, poor weather prevented taking all of the samples. Samples in the water lily beds were taken during periods of high striped bass density (determined by ongoing river collections). A 250 µm mesh net with a mouth area of 0.085 m^2 was held 15 cm under the water surface at the bow of a small outboard-powered boat and pushed through the water lily beds. This mesh size may not have collected the smallest zooplankters (e.g. rotifers) but was used to avoid net clogging by suspended silt. Studies in 1985 with 90 µm mesh and 75 µm mesh nets had shown that these nets clogged with silt in less than two minutes (Rulifson, unpub. data). Samples were two minutes in duration and were generally done in pairs, one in an upstream direction and one downstream. On some sampling dates, poor weather prevented the taking of the second sample. The contents were washed into a collecting cup and preserved with 10% formalin containing rose bengal dye. Fish larvae were removed from each sample in the laboratory, identified (Table 2) and counted, and gut contents were examined from those larvae capable of feeding (determined by the presence of developed jaws and an inflated gas bladder). Zooplankton and organisms consumed by fish larvae were identified to the lowest practical taxon (Table 2) using Pennak (1978), McCafferty (1981), and Merritt and Cummins (1984). Densities of each taxon were estimated by calculating the theoretical volume of water filtered through the net (mouth area X distance traveled). To compensate for unequal sampling effort, densities were calculated for the total volume of each station/date combination. Comparisons of pushnet samples to river samples were made for zooplankton in May of 1987 and 1988 and for larval fish in May and June in 1987-1989. No river zooplankton samples were taken in June of 1987 or 1988 and no pushnet zooplankton samples were taken in 1989. Changes in personnel and sampling boat in 1989 may have reduced that year's apparent larval fish catch so it has not been included in statistical analyses. Larval fish river samples were taken with a single, conical 250 µm net as in Rulifson et al. (1988). Larval fish density comparisons were made between pushnet samples and the mean density of river samples generally taken on dates before and after the pushnet sample (Table 1). The following scheme was used for station comparisons: pushnet Station 7 with river Station 7, pushnet Station 8 with river Station 8, pushnet Station 12 with river Station 12 in each month except June 1989 when river Station 10 was used; pushnet Station 40 with river Stations 7 and 10 combined (there were no existing Stations in proximity to Station 40); pushnet Station 41 with river Station 9, and pushnet Station 42 with river Station 9.

Lighted Fishtraps

In 1989, utilization of water lily beds by larval and juvenile fish was also estimated by collections from lighted fish traps. A total of 18 minnow traps covered with 1.5 mm square wire mesh set 2 m apart was placed at three sites near Station 10. Water depth averaged 1m at each site. Six of the traps contained green Cyalume lightsticks, six contained red lightsticks, and the remaining six traps were without lightsticks to serve as controls. Each site received two traps containing each color lightstick and two traps without lightsticks (Figure 2). Traps were set at dusk and retrieved at dawn of the next day. Samples were taken at each site on 3, 6, 9, 23, 24, 26, 30, and 31 of May and 3, 6, 10, and 13 of June for a total of 216 samples. Collected organisms were preserved as above and returned to the laboratory. Gut analysis was done on those fish

Table 1. Dates of pushnet sampling, number of samples, and dates of comparative river samples, 1987-1989.

Station	1987		1988		1989	
7		6-08 (4)		6-08 (2)		6-12 (1)
8	5-13 (2)	6-08 (2)		6-08 (1)	5-25 (1)	6-12 (2)
12	5-13 (2)	6-08 (2)	5-23 (2)	6-08 (2)	5-25 (1)	6-12 (1)
40			5-23 (1)	6-07 (2)		
41			5-23 (2)			
42	5-13 (1)					
Total samples	13		12		6	
River sample dates	5-12 5-14	6-05 6-07	5-22 5-26	6-03	5-25 5-27	6-08 6-12

Table 2. List of larval fish taxa and zoopankton taxa collected in pushnet samples, 1987-89.

	Larval fish	Zooplankton
Scientific name	Common name	Scientific name
Anguilla rostrata	American eel	Rotatoria
Herring	Nematoda	
Brevoortia tyrannus	Atlantic menhaden	*Stylaria* sp.
Notropis sp.	Minnows	*Aeolosoma* sp.
Cyprinus carpio	Carp	*Dero* sp.
Catastomidae	Suckers	Cladocerans[1]
Ictalurus nebulosus	Brown bullhead	*Daphnia* sp.
Aphredoderus sayanus	Pirate perch	*Bosmina* sp.
Menidia beryllina	Inland silverside	Copepoda
Morone americana	White perch	Ostracoda
Morone saxatilis	Striped bass	Gammaridae
Centrarchidae	Sunfish	Isopoda
Percidae	Darters	Collembola
Perca flavescens	Yellow perch	Plecoptera
Strongylura marina	Atlantic needlefish	Ephemeroptera nymph
		Hemiptera
		Gerridae
		Megaloptera
		Trichoptera
		Coleoptera
		Gyrinidae
		Diptera larvae
		Diptera adult
		Chironomidae
		Heleidae
		Gastropoda
		Arachnida
		Hydra sp.

[1]Cladocerans do not include *Daphnia* sp. or *Bosmina* sp.

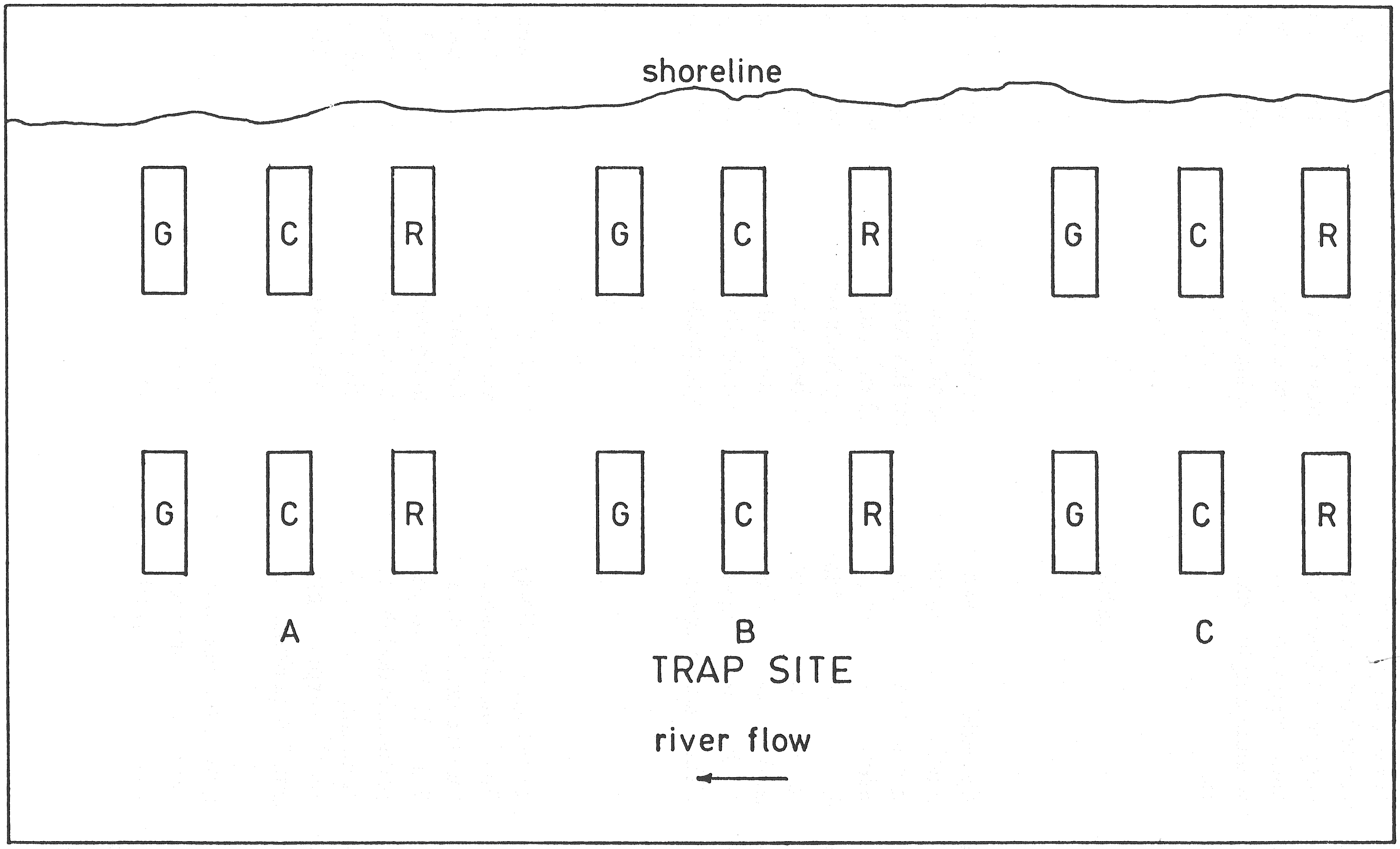

Figure 2. Schematic arrangement of fish traps at Station 10 in the Roanoke River. G = green lightstick; C = control (no lightstick); R = red.

capable of feeding.

To determine whether vegetative type played a role in utilization of submerged macrophytes, an artificial seagrass bed (2.5 x 3.0 m) was positioned near shore and was constructed of astroturf with equally-spaced groups of eight monofilament strands (Berkeley Fish-Hab) extending 1.0 m above the river bottom. Each group of strands was 35 cm apart (16/m^2). The seagrass bed was placed among water lilies adjacent to the three fish trap sites and was sampled with illuminated and non-illuminated fish traps. Three traps, one containing a red lightstick, one containing green, and one without a lightstick, were fished on the same dates as the other three sites for a total of 36 samples.

RESULTS

Water Lily Beds

The largest water lily beds in each year were found at Stations 7, 8, and 12. The other three Stations had approximately one-fifth of the lowest value of Stations 7, 8, and 12 (Table 3). The Cashie River had the greatest average coverage of water lily beds (3166 m^2) followed, in decreasing order, by the Eastmost (1570 m^2), Roanoke (662 m^2) and the Middle (598 m^2). In 1989, the Roanoke and Middle Rivers had larger water lily beds on the left shore (facing upstream) than on the right shore. The Cashie River water lily beds were of nearly equal size on both shores and the Eastmost River had small water lily beds only on the right side, and scattered individual plants on the left side. The average dimensions of water lily beds in each distributary are summarized in Table 4. The water temperatures and times of pushnet samples are shown in Figure 3.

Pushnets

The largest number of fish larvae (1094) was collected in 1987 (the flood year), followed by 484 in 1988 and 21 in 1989. The dominant taxon in 1987 and 1988 was sunfish accounting for 50.8% and 82.4% of the total catch in the respective year. Herring was second in abundance in these two years at 39.1% and 12.2%, respectively. The remainder was divided between 14 other taxa (Table 5). *Notropis* dominated the catch in 1989 (66.6%). Only one striped bass was collected during the three sampling periods. Sunfish and herring dominated the total catch in density (4.3 and 2.2 larvae/m^3, respectively) and percent abundance (60.0% and 30.4%, respectively) for the three sampling periods.

There was a significant difference in larval fish catch by tow direction (combined totals from 1987 and 1988; Wilcoxon's rank sum test P=0.04) with nearly three times as many larvae collected in downstream tows. This was attributed to five large catches of larvae: 376 herring (one sample, May 1987; 77.2% of total collected); and 517 sunfish (three samples in June 1987 and one sample in June 1988; 53.9% of total collected). There was no significant difference in

Table 3. Water lily bed size (m^2) at pushnet sampling stations.

Year	Station 7	12	8	41	40	42
1987	39750	7200	18280	900	150	850
1988	37500	6800	17500	600	100	750
1989	32600	7000	13975	840	150	1300

No sign. diff. between years (AOV, F=2.05, P=0.1796)

Table 4. Average water lily bed areas (m) on each bank (facing upstream) in the Roanoke River and distributaries in 1989.

Bank	Roanoke	Middle	Eastmost	Cashie
right	4.2 X 44.0	3.4 X 73.1	7.3 X 226.6	11.3 X 313.0
left	6.2 X 75.6	6.1 X 198.7	scattered	11.9 X 294.0
average	5.2 X 59.8	4.7 X 135.9	--	11.5 X 303.5
mean surface area (m^2)	662	598	1570	3166

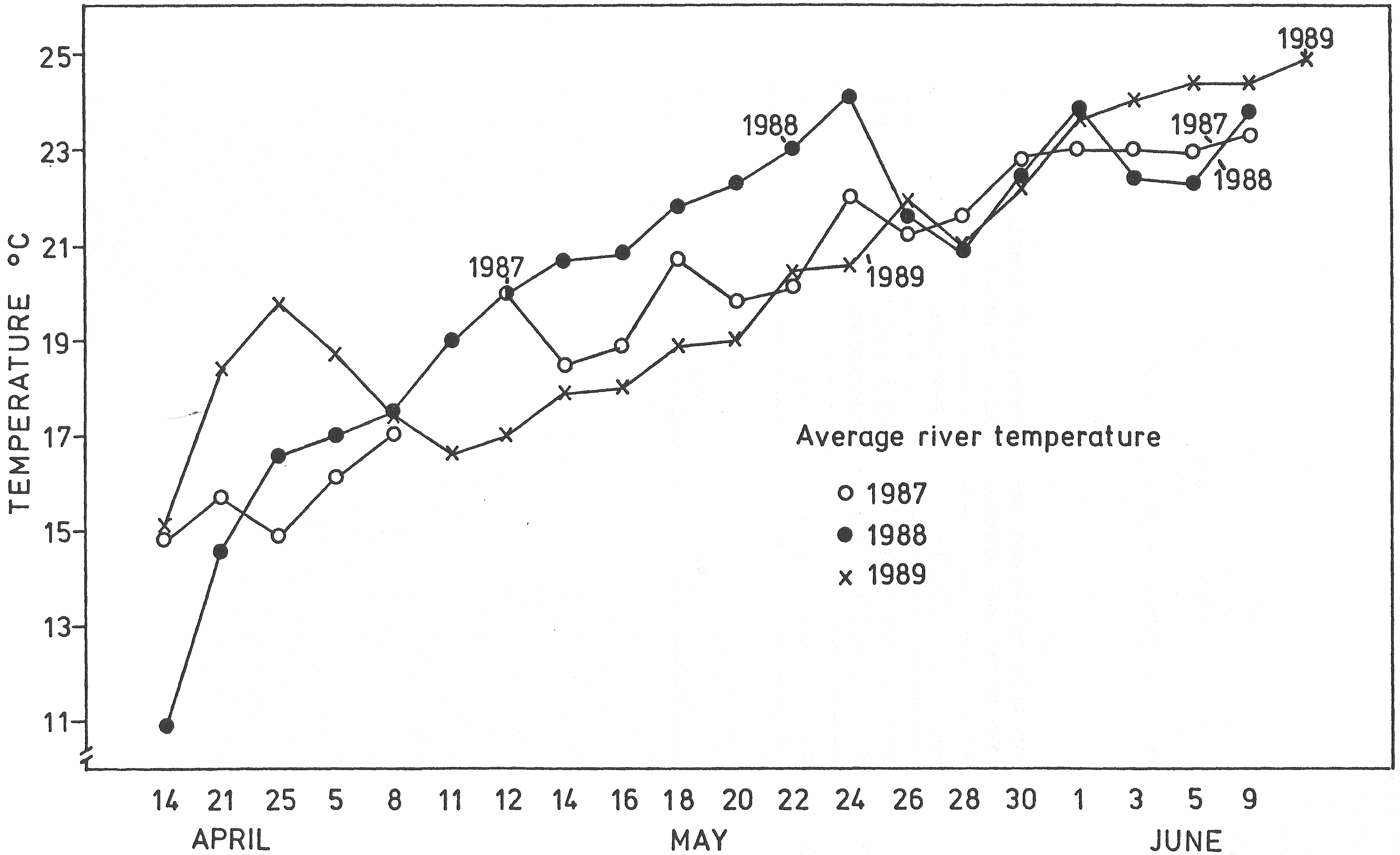

Figure 3. Water temperatures and times of pushnet sampling in water lily beds.

Table 5. Fish taxa collected by pushnet in water lily beds, 1987-89. All stations combined.

Taxa	N	1987 Mean TL	Range TL	N	1988 Mean TL	Range TL	N	1989 Mean TL	Range TL	Total	Density (N/m3)	Density (N/m3)
Sunfish	556	6.5	4.0-15.0	399	5.5	4.0- 8.0	4	6.0	5.0- 7.0	959	4.3	4.30
Herring	428	9.3	3.5-17.0	59	8.5	4.0-13.0	0			487	2.2	2.18
Notropis sp.	41	9.1	5.0-17.0	5	8.5	6.0-17.0	14	23.4	19.0-31.5	60	0.3	0.27
White perch	40	3.5	2.5- 4.5	1	2.0		0			41	0.2	0.18
Darters	8	5.2	5.0- 5.5	10	9.0	4.5-17.0	1	19.0		19	0.1	0.09
Menhaden	10	38.2	34.0-42.0	0			0			10	<0.1	0.04
Carp	5	7.3	6.5- 8.0	0			1	7.0		6	<0.1	0.03
American eel	1	56.5		1	55.0		1	60.0		3	<0.1	0.01
Pirate perch	0			2	12.5	9.0-16.0	0			2	<0.1	0.01
Atl. needlefish	1	17.0		0			0			1	<0.1	0.00
Brown bullhead	1	22.0		0			0			1	<0.1	0.00
Striped bass	0			1	6.0		0			1	<0.1	0.00
Suckers	0			1	16.0		0			1	<0.1	0.00
Inland silverside	0			1	4.0		0			1	<0.1	0.00
Yellow perch	2	7.7	7.0- 8.5	0			0			2	<0.1	0.01
Unidentified	1			4	5.5		0			5	<0.1	0.02
Total	1094	7.9		484	6.1		21	20.8		1599	7.2	7.16

catch for individual taxa by tow direction, therefore the following analysis has been made on the combined upstream and downstream samples.

Seasonality of the catches was apparent for three of the four species of which at least 20 individuals were caught. All white perch and 93.6% of the herring were collected in May while 92.3% of the sunfish were collected in June. *Notropis* were divided nearly equally between May (46%) and June (54%).

Excluding the large collections of sunfish and herring made during 1987 and 1988, pushnet collections were not significantly greater in larval density than comparable collections made in the river ($t=1.96$, $p=0.06$, $df=25$). Striped bass were collected only once in water lily beds (one larva, Station 12, June 1988) although striped bass densities averaged $1.02/m^3$ in the river during comparable periods in 1988 and $0.03/m^3$ in 1989 (Table 6). No striped bass larvae were collected on comparable dates in the river in 1987 due to high river flow.

Lighted Fish Traps

Forty-five fish were collected in 11% (24) of the 216 samples taken. Nearly half (47%) of these fish were collected in the first three sample dates. The majority of all fish caught were darters (77.8%); the remainder was two brown bullhead, and one each of eastern mudminnow, bluegill, *Notropis*, chain pickerel, bay anchovy, carp, largemouth bass, and yellow perch. No striped bass were caught in the lighted fish traps. The range in total length for all fish was 11.0 to 60.0 mm and the mean was 21.1 mm. Less than half (23) of all fish caught could be classified as larvae (based on development) and 87% of these were darters (mean length was 11.7 mm). The larval stage (as defined by Snyder 1976) of darters in the Roanoke River generally ends when the fish reach 16.0 mm in total length.

Twenty-five of the 45 (55.5%) fish collected were taken in traps illuminated with red lightsticks, 17 (37.8%) in green-lightstick illuminated traps, and the remainder (6.7%) in the control traps. The lightstick traps caught significantly more fish than the control traps ($X^2=16.52$, $df=2$, $P=0.005$) but there was no significant difference in catch between the red and green lightstick traps. Significantly more fish were caught at site C than either site A or B ($X^2=22.8$, $df=2$, $P=0.005$). There was no significant difference between sites A and B.

Artificial Seagrass

Three of the 36 samples (8.3%) from the artificial seagrass bed contained fish: 7 darters ($x=13.8$ mm TL), one *Notropis* (14.0 mm TL), and one chain pickerel (32 mm TL). Six darters and one *Notropis* were captured in the red lightstick trap, one darter and one chain pickerel in green, and none in the control trap. These fish were collected within the same time interval as the majority of those collected at the other three sites. Each set of traps caught nearly an equal number of fish per trap (Station 10 = 0.25; seagrass = 0.21).

Table 6. Comparison of larval fish density (N/m3) in water lily beds and adjacent river stations, 1987-1989

May 1987

TAXA	W. lily 5-13 Sta 8	river 2-day mean	W. lily 5-13 Sta 42	river 2-day mean	W. lily 5-13 Sta 12	river 2-day mean	Grand mean W. lily	Grand mean river
Herring	26.40	0.87	1.90	1.96	1.00	2.02	9.77	1.62
White perch	0.30	0.82	0.60	1.12	2.20	0.81	1.03	0.92
Sunfish	0	0.02	0.30	0	0	0.05	0.10	0.02
Atl. menhaden			0	0.02	0.70	0	0.23	0.01
Darters			0	0.04	0.30	0	0.10	0.01
Notropis sp.	0.10	0.16	0.10	0	1.00	0.03	0.40	0.06
Carp	0	0.03	0.10	0	0.10	0	0.07	0.01
American eel					0.10	0	0.03	0

June 1987

TAXA	W. lily 6-08 Sta 8	river 2-day mean	W. lily 6-08 Sta 7	river 2-day mean	W. lily 6-08 Sta 12	river 2-day mean	Grand mean W. lily	Grand mean river
Herring	0.60	0.37	0.30	0.04	0.10	0.03	0.33	0.15
Sunfish	10.30	0.04	12.10	0.97	4.00	0.02	8.80	0.34
Darters			0.10	0			0.03	0
Notropis sp.	1.40	0.02	0.10	0	0.10	0	0.53	0.01
Carp	0.10	0			0	0.13	0.03	0.04
Brown bullhead					0.10	0	0.03	0
Atl. needlefish	0.10	0					0.03	0
Yellow perch			0.10	0			0.03	0

May 1988

TAXA	W. lily 5-23 Sta 12	river 2-day mean	W. lily 5-23 Sta 40	river 2-day mean	W. lily 5-23 Sta 41	river 2-day mean	Grand mean W. lily	Grand mean river
Herring	3.10	0.06	0.30	0.12	0.10	0.23	1.17	0.14
White perch	0.10	0	0.00	0.03	0	0.55	0.03	0.19
Sunfish	0.10	0.04	8.30	0.10	0.80	0.02	3.07	0.05
Darters	0.10	0	0.30	0.00	0.40	0	0.27	0
Notropis sp.	0.10	0	0.40	0.01	0.10	0.06	0.20	0.02
Suckers			0	0.01	0.10	0	0.03	<0.01
Striped bass	0	0.08	0	0.15	0	0.04	0	0.09
Atl. menhaden	0	0.04						0.01

Table 6. (Continued)

June 1988

TAXA	W. lily 6-03 Sta 12	river 2-day mean	W. lily 6-03 Sta 40	river 2-day mean	W. lily 6-03 Sta 7	river 2-day mean	W. lily 6-03 Sta 8	river 2-day mean	Grand mean W. lily	Grand mean river
Herring	0.4	0.26	0.30	0.19	0.20	0.06	0.10	0	0.25	0.13
Sunfish	1.9	0	8.10	0	12.60	0	1.00	0	5.90	0
Darters	0.1	0	0	0					0.03	0
Striped bass	0.1	0.06	0	0.02					0.03	0.02
Atl. menhaden	0	0.06	0	0.02			0	0.10	0	0.05
Inl. silverside			0.10	0					0.03	0

May 1989

TAXA	W. lily 5-25 Sta 8	river 2-day mean	W. lily 5-25 Sta 12	river 2-day mean	Grand mean W. lily	Grand mean river
Herring	0	0.10	0	0.29	0	0.19
White perch	0	0.10	0	0.04	0	0.07
Darters	0	0.04	0.10	0.02	0.05	0.03
Notropis sp.	0	0.02			0	0.01
American eel	0.10	0			0.05	0
carp			0.10	0	0.05	0

June 1989

TAXA	W. lily 6-12 Sta 7	river 2-day mean	W. lily 6-12 Sta 8	river 2-day mean	W. lily 6-12 Sta 12	river 2-day mean	Grand mean W. lily	Grand mean river
Herring	0	0.22	0	0.17	0	0.04	0	0.14
Sunfish	0.55	0.49			0	0.02	0.18	0.17
Darters	0	0.02					0	0.01
Notropis sp.			0.55	0.05	0.97	0	0.51	0.02
Striped bass	0	0.15	0	0.04	0	0.02	0	0.07
Morone sp.			0	0.01			0	<0.01
Pirate perch					0	0.02	0	0.01
Brown bullhead					0	0.02	0	0.01

Zooplankton

Six zooplankton taxa were collected during 1987 and 1988 that were considered to be potential prey for larval fish based on fish mouth gape and zooplankter size (maximum of 0.9 mm prey width): cladocerans; copepods (includes nauplii and copepodites); ostracods; *Daphnia*; rotifers; and *Bosmina*. Twenty-six taxa of zooplankton were identified in 1987 and seventeen taxa were identified in 1988 (Table 7). The following results will consider only the potential prey taxa.

Cladocerans (excluding *Bosmina* and *Daphnia*) dominated the zooplankton in pushnet samples in both years with a mean density of 701.4/m^3, at least nine times greater than any other taxa considered. The remaining five taxa (in decreasing density) were copepods (43.7/m^3), ostracods (9.4), *Daphnia* (7.9), rotifers (0.8), and *Bosmina* (0.2). The overall mean density of cladocera, *Daphnia*, and copepods was similar in pushnet samples in both years but this was not true of ostracods or rotifers. *Bosmina* were collected only once in pushnet samples. The relatively few samples examined from both pushnet and river stations resulted in high variability for all potential prey taxa in May of both years except for cladocera in 1987 (Table 8). In general, zooplankton densities in the water lily beds were less than that found in the river.

Gut Analysis

Cladocerans and rotifers were the dominant prey consumed by fish in pushnet samples in 1987 and 1988 (Tables 9 and 10). *Bosmina* ranked third in percent consumed in 1987 and 1988. In 1987, rotifers were the preferred food of sunfish, herring, *Notropis*, white perch, and Atlantic needlefish. Sunfish preferred the same taxa in 1988 but *Notropis* preferred cladocerans. Herring contained no food in 1988 (white perch and Atlantic needlefish were not collected in 1988). Menhaden, darters, and yellow perch preferred cladocerans in 1987, but in 1988, darters consumed only *Bosmina*, a taxa they had not consumed in 1987. Menhaden and yellow perch were not collected in 1988. Carp consumed more *Bosmina* than any other prey taxa and brown bullhead consumed primarily copepods and cladocerans. In 1987, approximately 25% of the fish examined had no food and 90% in 1988 had no food. The six samples taken in 1989 contained 21 fish, 17 of which consumed only detritus (14 *Notropis*, mean TL=23.4; one darter, 19.0 mm TL; one carp, 7.0 mm TL; one American eel, 60.0 mm TL). The remaining four fish (sunfish, mean TL=6.0 mm) had no food in their guts. In May of 1987 and 1988, the abundance of potential prey zooplankton taxa was reflected to some degree in the prey taxa ingested in the river and in the water lily beds. In both years, cladocera and rotifers were preferred but only cladocera were abundant in zooplankton samples. Diptera larvae were not considered to be a potential prey item and never ranked more than fourth in prey consumed.

The most numerous prey taxa consumed by fish caught in the lighted fish traps was cladocerans (40.5% of total consumed) with diptera larvae second at 20.3%. Cladocerans were

Table 7. Zooplankton density (N/m3) in water lily beds at pushnet stations, 1987-1988

	1987						
	May 13			June 8			
Station	8	12	42	7	8	12	mean density
Cladocera	164.3	145.8	189.8	2715.3	2907.4	837.9	1160.1
Stylaria sp.	16.2	9.3	4.7	136.6	275.5	11.5	75.6
Diptera larva	11.6	12.7	13.9	147.0	47.4	130.8	60.6
Copepoda	11.6	13.9	27.8	18.5	52.1	0	20.6
Ostracoda	7.0	2.3	9.3	4.7	85.7	4.7	18.9
Aeolosoma sp.	7.0	0	0	35.9	51.0	0	15.6
Gammaridae	4.6	13.9	37.0	5.8	7.0	4.7	12.2
Daphnia sp.	4.7	11.5	0	5.8	48.6	0	11.8
Dero sp.	0	2.3	0	11.5	11.5	9.3	5.8
Arachnida	2.3	0	0	3.5	13.9	11.5	5.2
Unidentified	4.7	4.7	4.7	2.3	2.3	2.3	3.5
Heleidae	0	0	0	0	13.9	0	2.3
Chironomidae	0	0	0	3.5	7.0	0	1.7
Rotatoria	9.3	0	0	0	0	0	1.6
Hydra sp.	4.7	0	0	0	4.7	0	1.6
Ephemeroptera	0	0	4.7	2.3	2.3	0	1.5
Collembola	2.3	2.3	0	1.2	0	0	1.0
Diptera adult	0	0	0	0	4.7	0	0.8
Coleoptera	0	0	0	3.5	0	0	0.6
Plecoptera	0	0	0	0	2.3	0	0.4
Megaloptera	2.3	0	0	0	0	0	0.4
Nematoda	0	0	0	2.3	0	0	0.4
Gyrinidae	0	0	0	2.3	0	0	0.4
Trichoptera	0	0	0	0	2.3	0	0.4
Gastropoda	0	0	0	1.2	0	0	0.2
Bosmina sp.	0	0	0	1.2	0	0	0.2

	1988							
	May 23			June 7			June 8	
Station	40	12	41	40	7	8	12	Mean density
Cladocera	319.4	125.0	152.8	39.4	435.2	203.7	423.6	242.7
Copepoda	4.6	23.1	30.1	11.6	69.5	37.0	291.7	66.8
Aeolosoma sp.	9.3	4.7	9.3	2.3	46.3	289.3	7.0	52.6
Diptera larvae	23.1	4.6	12.8	20.9	63.6	168.2	56.9	50.0
Stylaria sp.	0	0	0	4.7	2.3	122.7	0	18.5
Gammaridae	27.8	0	2.3	4.7	13.9	0	44	13.2
Ostracoda	0	0	0	4.7	7.0	2.3	39.4	7.6
Gerridae	41.7	0	0	2.3	0	0	0	6.3
Daphnia sp.	4.6	0	16.2	2.3	2.3	0	2.3	4.0
Chironomidae	0	9.3	2.3	0	0	2.3	0	2.0
Unidentified	0	9.3	0	2.3	0	0	2.3	2.0
Arachnida	0	0	0	0	0	2.3	9.3	1.7
Hemiptera	0	0	7.0	0	0	2.3	0	1.3
Isopoda	0	0	0	0	0	0	4.7	0.7
Ephemeroptera	4.6	0	0	0	0	0	0	0.7
Hydra sp.	4.6	0	0	0	0	0	0	0.7
Nematoda	0	0	0	0	2.3	0	0	0.3

Table 8. Comparisons of potential zooplankton prey densities (N/m3) in May collections from pushnet stations and adjacent river stations.

TAXA	w. lily 5-13 sta 8	river 2-day mean	w. lily 5-13 sta 42	1987 river 2-day mean	w. lily 5-13 sta 12	river 2-day mean	Grand mean w. lily	std	C.V.	Grand mean river	std	C.V.
cladocera	164.3	199.3	189.8	237.1	145.6	136.7	166.6	18.1	11%	191.0	67.0	35%
Daphnia	4.6	62.5	0	43.7	11.5	57.8	5.4	4.7	82%	54.7	22.6	41%
copepods	11.6	72.3	27.8	22.5	13.9	17.0	17.8	7.2	40%	37.3	32.1	86%
Bosmina	0	19.3	0	24.9	0	13.7	0			19.3	7.3	38%
ostracods	7.0	3.8	9.3	1.8	2.3	4.4	6.2	2.9	47%	3.3	1.2	36%
rotifers	9.3	0	0	0	0	0	3.1			0		
Total	196.8	357.2	226.9	330.0	173.3	229.6	199.0			305.6		

TAXA	w. lily 5-23 sta 40	river 2-day mean	w. lily 5-23 sta 12	1988 river 2-day mean	w. lily 5-23 sta 41	river 2-day mean	Grand mean w. lily	std	C.V.	Grand mean river	std	C.V.
cladocera	319.4	5.9	125.0	4.2	152.8	34.1	199.1	85.8	43%	14.7	19.8	135%
Daphnia	4.6	34.3	0	157.4	16.2	91.8	6.9	6.8	98%	94.5	82.7	87%
copepods	4.6	66.2	23.1	77.6	30.1	142.9	19.3	10.8	56%	95.6	39.2	41%
Bosmina	0	14.1	0	46.4	0	70.2	0			43.6	40.6	93%
ostracods	0	0.7	2.3	0	0	5.4	0.8	1.1	137%	2.0	3.4	170%
rotifers	0	0	0	0.8	0	0	0			0.3		
Total	328.6	121.2	150.4	286.4	199.1	344.4	226.0			250.7		

Table 9. Percent of prey taxa consumed (and number of organisms) by larval fish in pushnet samples, 1987.

		Prey taxa										
Fish taxa	N	Cladocerans	Rotifers	Bosmina sp.	Copepoda	Diptera larvae	Gammaridae	Fish	unident.	detritus1	Total consumed	Fish with no food
Sunfish	172	27.1 (104)	64.3 (247)	6.5 (25)	0.8 (3)	0	0	0.3 (1)	1.0 (4)	65.7 (113)	100 (384)	33.0 (57)
Herring	44	4.9 (4)	70.1 (58)	19.5 (16)	0	0	0	0	4.9 (4)	77.3 (34)	100 (82)	9.5 (4)
Notropis sp.	18	4.9 (4)	84.1 (69)	11.0 (9)	0	0	0	0	0	84.1 (16)	100 (82)	5.5 (1)
Menhaden	8	80.0 (270)	0	8.0 (27)	6.2 (21)	3.8 (13)	0	0	1.8 (6)	100 (8)	100 (337)	0
Darters	4	80.0 (4)	20.0 (1)	0	0	0	0	0	0	0	100 (5)	25.0 (1)
Yellow perch	2	75.0 (3)	0	0	0	25.0 (1)	0	0	0	50.0 (1)	100 (4)	0
Carp	2	0	0	83.3 (20)	16.7 (4)	0	0	0	0	100 (2)	100 (24)	0
Atl. needlefish	1	0	100 (6)	0	0	0	0	0	0	100 (1)	100 (6)	0
White perch	1	0	83.3 (5)	0	0	0	0	0	16.7 (1)	0	100 (6)	0
Brown bullhead	1	33.3 (8)	0	0	41.7 (10)	16.7 (4)	8.3 (2)	0	0	100 (1)	100 (24)	0
American eel	1	0	0	100 (1)	0	0	0	0	0	100 (1)	100 (1)	0
Percent of total		35.1	34.1	8.6	3.3	1.6	0.2	0.1	1.3	69.7	100	24.8
Total	254	(397)	(386)	(98)	(38)	(18)	(2)	(1)	(15)	(177)	(955)	(63)

1Percent of fish larvae (number counted) wuth detritus.

Table 10. Percent of prey taxa consumed (and number of organisms) by larval fish in pushnet samples, 1988.

		Prey taxa							
Fish taxa	N	Cladocerans	Rotifers	Bosmina sp.	Copepoda	Diptera larvae	detritus[1]	Total consumed	Fish with no food
Sunfish	238	0	80.5 (33)	19.5 (8)	0	0	3.4 (8)	(41)	92.0 (219)
Herring	53	0	0	0	0	0	0	(0)	100 (53)
Darters	7	0	0	63.6 (7)	27.3 (3)	9.1 (1)	71.4 (5)	(11)	14.3 (1)
Notropis sp.	5	100 (2)	0	0	0	0	40.0 (2)	(2)	60.0 (3)
Pirate perch	2	65.0 (13)	0	0	25.0 (5)	10.0 (2)	0	(20)	0
Striped bass	1	0	0	0	0	0	0	(0)	100 (1)
Suckers	1	0	0	0	0	0	100 (1)	(0)	0
American eel	1	77.8 (7)	0	0	0	22.2 (2)	0	(9)	0
Percent of total		26.5	39.7	18.1	9.6	6.0	5.2	100	89.9
Total	308	(22)	(33)	(15)	(8)	(5)	(16)	(83)	(277)

[1]Percent of fish larvae (number counted) with detritus.

the dominant taxa consumed (39.5%) in all traps combined, gammarids were second at 27.0% and diptera larvae were third at 15.7%. The remaining taxa were fish (5.6%), leeches (3.4%), copepods (1.1%) and diptera adults (1.1%). Unidentified organisms accounted for 3.4% of the 88 organisms counted. Darters preferred gammarids (34%) but also consumed clasdocerans (18%) and diptera larvae (8%). The remaining fish taxa were collected in numbers too low to make any prey preference determination.

Cladocerans accounted for 89% of the prey organisms (one unidentified organism) consumed by fish collected in the artificial seagrass. Two of the fish larvae (*Notropis* and darter) had no food; six of the seven darter guts contained detritus.

Rotifers were the most preyed upon taxa in both water lily beds (39.7%) and in the river (59.6%). Cladocerans and copepods were second in the water lily beds (26.5%) and river (20.6%), respectively. *Bosmina* was third in both areas at 18.1% (water lily beds) and 8.8% (river). The above four taxa accounted for 95% of the prey consumed in the river samples and 94% of the prey consumed in the water lily bed samples (Table 11). The remaining prey percentage was shared by nine other taxa in the river and two taxa in the water lily beds.

DISCUSSION

Water lilies (*Nuphar*) were the dominant form of emergent vegetation in the lower Roanoke River Delta. Although water lily beds can be found throughout the river, the most extensive beds were formed in relatively quiet areas, generally in large bends of the river. The regulation of water discharges by the Roanoke Rapids Dam has reduced the spring floods in the delta which would normally scour out much of the accumulated sediments (Riggs et al. 1991). The retention and increasing accumulation of these sediments has allowed the water lily beds to become established. The regulation of water flow, which has in general prolonged flooding and low flow conditions in the delta (Ellis 1991), would determine the emergence time of water lilies because of water depth and moderation of solar heating of the water. A longer growth period would be required in high flows and lower water temperature before emergence and would produce longer stemmed plants. In low flow conditions when water is withheld behind the dams, rapid water temperature increases and lower depth would allow the plants to emerge at a much earlier date. Subsequent decreases in flow in high flow periods and decreasing water level would allow the leaves to be less tightly grouped and would increase the estimate of surface water lily bed size by the methods we used. Conversely, increasing water levels after the water lily leaves have emerged may resubmerge the leaves and allow them to become covered with fine silt, shading out many plants (Wetzel 1975) and lowering the estimate of bed size. These factors may have decreased the estimate for 1987: the mean daily river discharge was 27,000 cfs in the month preceding the estimate and this may have allowed many plants to remain undetected. Low flows (mean daily discharge of 2250 cfs) and cool spring temperature during the month before the 1988 estimate may have also decreased this estimate: the low flow would normally have allowed rapid plant growth but was inhibited by the low temperature. The estimate for 1989

Table 11. Percent of prey taxa consumed (and number of organisms)by larval fish in selected river samples, 1988.

Fish taxa	N	Prey taxa: Cladocerans	Rotifers	Bosmina sp.	Copepoda	Copepoda egg	Diptera larva	Gammaridae	Ostracoda	Arachnida
Striped bass	361	4.9 (2)	0	65.8 (27)	12.2 (5)	12.2 (5)	2.4 (1)	0	2.4 (1)	0
Atl. menhaden	157	4.0 (46)	64.4 (747)	6.5 (75)	22.7 (263)	0	0	0	0.2 (2)	0
Herring	75	2.6 (2)	57.9 (44)	19.7 (15)	15.8 (12)	0	0	0	1.3 (1)	0
Sunfish	34	25.0 (1)	25.0 (1)	50.0 (2)	0	0	0	0	0	0
Notropis sp.	29	5.0 (12)	67.3 (74)	1.8 (2)	13.6 (15)	0	0.9 (1)	0.9 (1)	0	0.9 (1)
White perch	12	0	0	63.6 (7)	9.0 (1)	0	9.0 (1)	0	0	0
American eel	5	92.3 (12)	0	0	0	0	0	7.7 (1)	0	0
Brown bullhead	3	13.3 (2)	0	0	0	0	13.3 (2)	13.3 (2)	0	0
Morone sp.	3	0	0	0	0	0	0	100 (12)	0	0
Darters	1	70.0 (7)	0 0	0 0	30.0 (3)	0	0	0	0	0
Percent of total Total	 680	5.8 (84)	59.6 (866)	8.8 (128)	20.6 (299)	0.3 (5)	0.3 (5)	1.1 (16)	0.3 (4)	<0.1 (1)

1Percent of fish larvae (number counted) with detritus.

Table 11. (Continued)

Fish taxa	Cladocera egg	Clams	unident	Diptera adult	detritus1	Total consumed	Fish with no food
Striped bass	0	0	0	0	0	(41)	91.4 (330)
Atl. menhaden	1.0 (12)	0	0.4 (5)	0.9 (10)	97.4 (153)	(1160)	0
Herring	0	0	2.6 (2)	0	1.3 (1)	(76)	81.3 (61)
Sunfish	0	0	0	0	5.9 (2)	(4)	82.3 (28)
Notropis sp.	0	0	3.6 (4)	0	20.7 (6)	(110)	13.8 (4)
White perch	9.0 (1)	0	9.0 (1)	0	8.3 (1)	(11)	33.3 (4)
American eel	0	0	0	0	20.0 (1)	(13)	40.0 (2)
Brown bullhead	0	60.0 (9)	0	0	33.3 (1)	(15)	0
Morone sp.	0	0	0	0	0	(12)	33.3 (1)
Darters	0	0	0	0	0	(10)	0
Percent of total Total	0.9 (13)	0.6 (9)	0.8 (12)	0.7 (10)	24.2 (165)	100 (1452)	63.2 (430)

(made in August at a relatively high temperature) may be lower than what would be found in spring since some water lily plants were dying back, but there was no statistically significant difference between years in our estimates.

Fifteen taxa of fishes were collected but of these only three can be described by our data as utilizing the water lily beds: sunfish, which spawn in shallow areas, darters, and *Notropis*. Herring and white perch were collected only in May (the majority in high river flow conditions) and inconsistently afterward, so therefore were not considered to be resident in the water lily beds. Larval striped bass do not utilize the water lily beds, apparently being carried through the lower delta by the strength of the river current. It may be that striped bass, white perch, and herring do not attain a size (prior to reaching Albemarle Sound) that enables them to migrate out of the current to the water lily beds. Most fish larvae depend upon drift to reach the nursery areas and are not well equipped to migrate out of currents (Marcy 1976).

The larval and juvenile fish collected in this study occurred at times of year that were similar to that found by Marcy (1976), Johnson and Edwards (1977), and Gerlach and Kahnle (1981), accounting for geographical differences. Our data differed from that of Floyd et al. (1984) in that we found a greater percentage of *Notropis* and darters in vegetated areas than in open water, similar to that of Conrow et al. (1990). Our data differed from that of Conrow et al. (1990) in that we collected more herring in open water. These differences in our data may be biased due to the short duration of the sampling periods but our samples were taken during high larval fish densities in the river. Our pushnet catch rate for larvae (1547/hr) was much higher than the 6.05/hr reported by Conrow et al. (1990) and, after accounting for the five unusually large catches, remained about 815/hr.

There is not universal agreement about the role of littoral areas on the production of zooplankton in comparison to more limnetic areas. Evidence of horizontal movement of zooplankton from the littoral zones to limnetic zones (Wetzel 1975) as a response to light intensity near the horizon, may suggest that the littoral areas may be less important in providing food for larval fish in lakes. If this movement is present in the Roanoke River, zooplankton collections taken in the center of the river would contain greater densities of zooplankton than would be found in the water lily beds due to the reduction in light over the shoreline horizon. From the perspective of a zooplankter, this would indicate the horizon to be toward the center of the river, away from the water lily leaves and overhanging trees. In addition, the presence of aquatic vegetation has been reported to exert a negative influence on zooplankton abundance (Hasler and Jones 1949; Pennak 1966, 1973). However, Wiley et al. (1984) did not find any evidence to show that zooplankton production was higher in limnetic than littoral areas. Jackson and Schmitz (1987) found no significant differences in densities of cladocerans, copepods, or rotifers between littoral and limnetic areas. Our zooplankton density estimates were highly variable due to the limited number of samples but we did find differences in taxa: greater densities of *Daphnia*, *Bosmina*, and copepods in river samples and greater densities of cladocera in water lily beds. These differences may reflect differing responses by these zooplankters to light and vegetation.

Larval fish feeding success was higher during periods of greater overall prey density. Rotifers, the primary taxa consumed, were rarely collected in zooplankton samples in water lily beds or the river. We cannot determine whether this was due to inadequate sampling (because of net mesh size), to naturally low populations, or to extensive grazing by predators. *Bosmina* was an important food source for larval fish and, although rarely found in water lily beds, was more abundant in river samples. Larval fish may have foraged at the fringes of the water lily beds where *Bosmina* were more abundant. Other cladocerans were not as important as a food source even though they were higher in density.

The fish traps we used were not an effective means to assess utilization of the water lily areas. The small mesh covering the trap may have allowed periphyton to become established over the trap surface, effectively dimming the light coming from the lightsticks. This would be supported by the relatively high catches (X=0.06/hr) in the first three sample dates which decreased to a mean of 0.006/hr over the remaining sample dates. This was also a factor in the low catches in fish traps used in the artificial seagrass. Catch rates for the traps was extremely low (0.02/hr) compared to 186/hr (Faber 1981), 51.9/hr (Floyd et al. 1984), and 1.4/hr for juvenile fish reported by Layzer and Clady (1991). These differences may be due to trap material as well as larval fish density: clear plexiglas traps with lights were used by Faber (1981) and Floyd et al. (1984); the lighted wire-mesh traps we used may have dimmed the apparent light even without periphyton fouling. Layzer and Clady used unlighted wire-mesh traps.

To be utilized, a vegetated area must reduce the vulnerability of the prey from predators (Cooper and Crowder 1979) and provide a source of food that can be used when foraging outside the area is not possible. In this regard, our artifical seagrass did not meet either criteria. The spacing of the artificial fronds within the seagrass (35 cm apart) was too far apart to entice larval fish to utilize the area. Savino and Stein (1982) determined that 14 cm between stems constituted low density vegetation and that there was no significant difference in predator behavior until stem density exceeded 50 stems per m^2. Vegetation density below this amount, as in our artificial seagrass ($16/m^2$), would not afford any protection to potential prey, thus there was no advantage in potential prey utilizing this area. In a study of macroinvertebrates in Iowa (Mrachek 1966), *Nymphaea* and *Nuphar* ranked tenth out of 11 plant species in the number of invertebrates found per kilogram (wet weight) of plant material. In the Roanoke River, Nuphar stems expose approximately 199 cm^2 per meter of stem while our artificial seagrass stems expose only 63 cm^2 per meter of stem. Thus three times as many artificial stems would be required to approximate that of the rather low-ranking water lily stem.

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SECTION III

INCIDENCE OF PARASITISM IN STRIPED BASS LARVAE COLLECTED FROM THE LOWER ROANOKE RIVER AND WESTERN ALBEMARLE SOUND, NORTH CAROLINA

by

John E. Cooper

INTRODUCTION

Altered river flow has been suggested as a cause for the low recruitment of striped bass (*Morone saxatilis*) juveniles in the Roanoke River due to its effect on the time and spatial juxtaposition of zooplankton and larval striped bass (Rulifson et al. 1988a). This asynchrony of predator and prey was hypothesized to result in larval fish starvation which, if true, may increase the impact of parasitism and predation on larval fish and subsequent recruitment of juveniles. Many parasites utilize fish larvae as hosts (Govoni 1983, Mozley 1984, Fischer and Kelso 1990) and can affect the physiology and survival of larval and juvenile fishes through: a) competition with the host for nutrients (Rosenthal 1967); and b) reducing the host weight and body condition (Gordon and Rau 1982; Lemly 1982; Moles 1983; Lemly and Esch 1984; Cunjak and McGladdery 1991).

If larvae are weakened by the direct effects of parasitism, they may also become more susceptible to predation by copepods. Predatory cyclopoid copepods are known to attack larval fish (Davis 1959; Fabian 1960; Lillelund and Lasker 1971; Smith and Kernehan 1981) and have been suggested as a significant, although sporadic, mortality factor for larval fish (Hartig et al. 1982).

This study examined larval and juvenile fishes present in the lower Roanoke River and western Albemarle Sound, North Carolina, for the prevalence and infestation intensity of plerocercoid larvae (Cestodes), metacercaria larvae (Trematodes), mussel glochidia (Unionacea), and predatory cyclopoid copepods (Crustacea).

METHODS

The larval fish examined in this study were taken from various parts of a series of striped bass distribution and feeding studies conducted from 1982 to 1991 in the lower Roanoke River and western Albemarle Sound (Figure 1). Collection methods for those studies have been described elsewhere (Rulifson 1984 and Section I of this report). In general, those collections were made every-other night (late May 1982; June 1983; early April through mid-June 1984-91): larval fish were collected using paired 0.5-m diameter 505 µm plankton nets towed in an oblique manner for six minutes; zooplankton collections were made with a single 0.5-m diameter 250 µm mesh plankton net towed just below the surface for two minutes. The collected fish and zooplankton were preserved in 10% borax-buffered formalin containing rose bengal dye. Fish larvae were identified using Lippson and Moran (1974), Auer (1982), and Olney et al. (1983), and measured to the nearest 0.5 mm total length. Alimentary tracts (esophagus to anus) were dissected from *Morone* sp. from all stations sampled from 1984-1991 and from other larval fish taken from a subset of stations in 1982-1985. Zooplankton and food items from dissected tracts were identified using Pennak (1978), McCafferty (1981), and Merritt and Cummins (1984).

In the present study, data for plerocercoids, metacercaria and glochidia for *Morone* were taken from a subset of the original samples taken in 1982 and 1983 and from all stations sampled

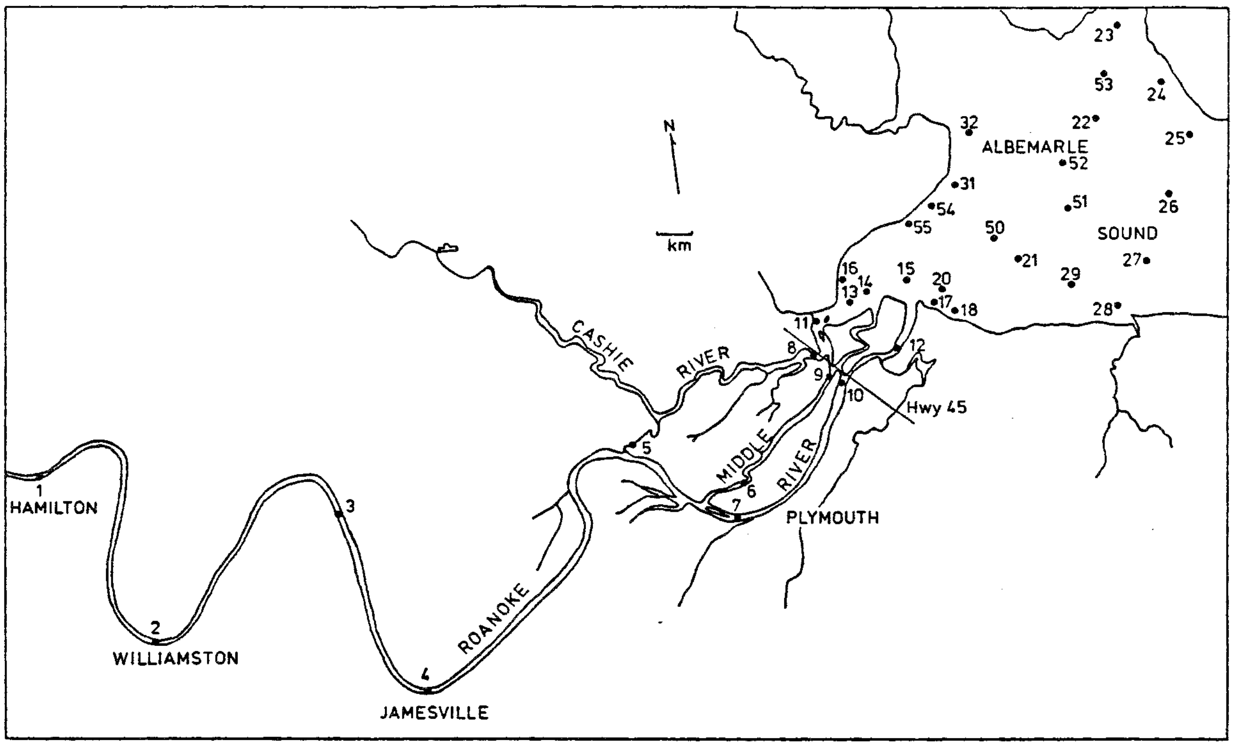

Figure 1. Composite of stations in the lower Roanoke River, delta, and western Albemarle Sound used for parasite and predator data, 1982-1986 and 1988.

in 1984 through 1986 and 1988. Few striped bass were collected in 1987; therefore, other larval fish were examined. For all other larval fish, data were collected as follows: plerocercoids, metacercaria, and glochidia were recorded from the same subset as for *Morone* in 1982 and 1983; plerocercoids, metacercaria, and glochidia from stations 1, 4, 7, 8, 10, 13 to 15 in 1984 and 1985; and glochidia from the same subset of stations in 1986 and 1988. Data on predatory copepods were taken from all stations sampled in 1986 and 1988. The number of samples and stations used are summarized in Table 1.

Plerocercoids were differentiated from metacercaria using the characteristics in Yamaguti (1959): scolex unarmed with four apical suckers, a fifth sucker sometimes present, no evidence of a ventral or oral sucker and parasites not enclosed by a cyst (identifications verified by David Zwerner, Virginia Institute of Marine Science). Specific identification was not attempted because of the limited development of the plerocercoid and metacercaria larvae. Glochidia were not identified but their identity was inferred by the presence or absence of adult mussels. Adult mussels were identified using Burch (1973) and Shelley (1987). Predatory copepods were identified using the methods described for zooplankton.

Plerocercoids were dehydrated in a graded ethanol series and slide-mounted in Euparal. Metacercaria were passed through a graded ethanol series (70%; 50%) and then stained for 24hrs in Grenacher's alcoholic borax carmine, destained in 50% ethanol and 70% acid alcohol, washed in 70%, 95%, and 100% neutral ethanol, cleared in xylene and slide-mounted in Preservaslide. Copepods were softened and stained in a solution of lactic acid and a few drops of picro acid fuchsin in chloral hydrate, rinsed in chloral hydrate, dissected in Hoyers mounting medium and sealed with ringing cement. Several copepods were also slide-mounted as whole mounts in Pro-Texx mounting medium after dehydrating in 100% isopropyl alcohol.

Parasites (plerocercoid and metacercaria larvae, glochidia in fish 25 mm TL or less) and predatory copepods were counted and their location in the host body recorded (Figure 2). Grid dimensions were changed to accommodate proportional changes in fish larvae so that each recorded position would be at the analogous morphological position. Attacks by predatory copepods were defined as an attached copepod having possession of part of the host tissue. The terms prevalence and intensity follow Margolis et al. (1982).

RESULTS

Plerocercoids

Plerocercoids varied in shape from triangular to oblate spheroid. Individuals ranged in size from 0.08 mm to 0.56 mm across the longest axis (X=0.20, SD=0.08, N=59) and from 0.08 mm to 0.48 mm across the shortest axis (X=0.20, SD=0.08, N=59). The developing scolex (Figure 3), when present, generally occupied one half of the body. Calcareous-like deposits were present but could not be differentiated from possible crystalline precipitation out of the formalin. In the present study, 96% of the plerocercoids were located in the gut cavity attached to the

Table 1. Number and location of samples examined for parasites and predators, 1982-1986, and 1988.

	YEAR							
STA	1982	1983	1984	1984	1985	1985	1986*	1988*
	all	fish	others	Morone	others	Morone	all	fish
1			13	14	13	14	22	32
2				14		14	22	30
3				14		14	22	20
4			14	14	14	14	22	28
5				22		30	34	22
6				22		40	34	30
7			22	22	37	40	34	30
8			28	28	36	40	34	32
9				28		40	34	26
10			24	28	37	40	34	40
11				28		40	34	24
12				28		40	34	24
13	3	7	27	28	36	36	28	22
14	5	6	21	26	32	36	30	
15	3	8	25	28	33	36	32	32
16				6		2		28
17				6				
18		1		6				12
20							6	2
21							6	12
22	4	7					6	8
23							4	6
24							6	6
26							6	8
28							6	8
31		1						12
32								12
50	2							
51	4							
52	2	2						
53	2	5						
54	1							
55	1							
TOTAL	27	37	174	362	238	476	490	506

*Only Morone were examined for plerocercoids and metacercaria

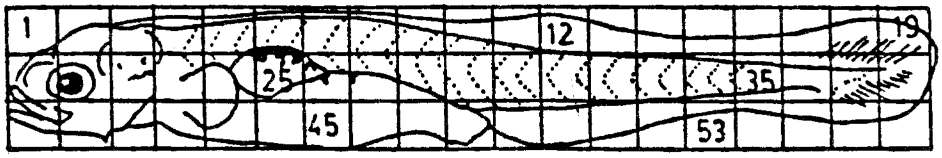

Figure 2. Larval fish body grid used for parasite and predator occurrence.

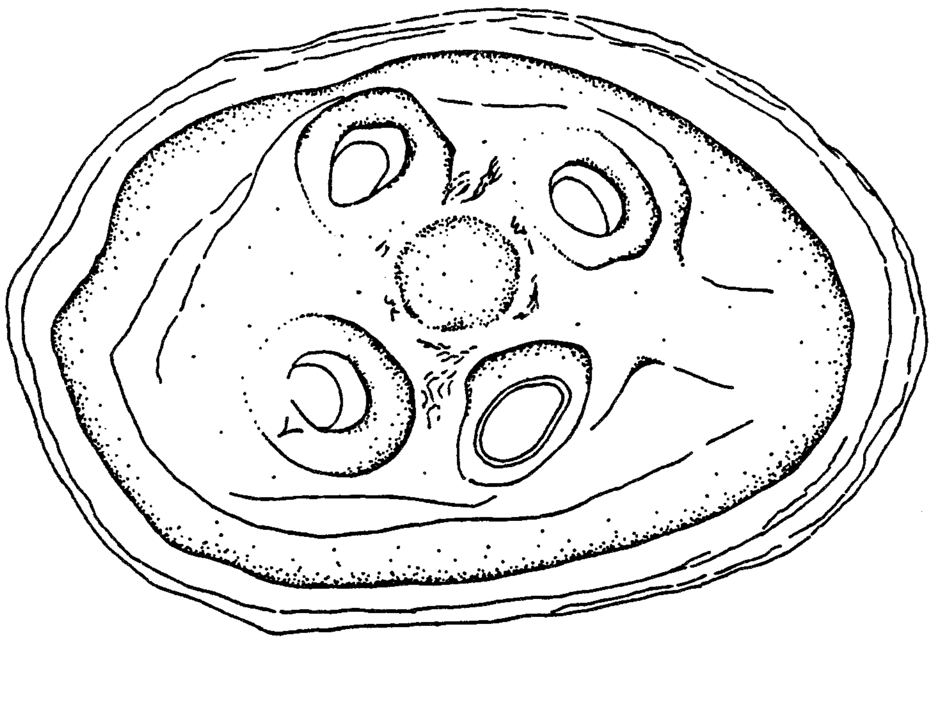

Figure 3. Developing scolex of plerocercoid from a striped bass.

intestine, liver, gas bladder, or mesentaries. The remainder was found in the tissue of the head (<1.0%), dorsal body (<0.5%), tail (<1.0%), and lower jaw (1.6%). Plerocercoids that occurred in the gut cavity were either attached directly to the host tissue (97%) or were free within the cavity, attached only by a slender thread. The characteristics of calcareous deposits and apparent preferred host body site is similar to that given by Yamaguti (1959) for *Proteocephalus*, but the limited development of the plerocercoids precluded any identification as to genus.

Twelve of the 25 taxa examined were parasitized by plerocercoids. In those taxa where 10 or more fish were examined, the highest prevalence was found in darters (9.8%), followed by *Notropis* (8.6%), and *Morone* (5.9%). The highest average intensity was found in sunfish (5.3%), followed by *Notropis* (4.5%), and white perch (3.7%, Table 2). Although the average intensity was 2.5, several individual larvae harbored a much greater number of plerocercoids: one *Notropis* at 13 mm TL had more than 90; one sunfish, 4.0 mm TL with 12, and a white perch, 23 mm TL, with 12.

Plerocercoid parasitism could occur soon after first feeding. The minimum observed size of parasitized fish larvae was 5.0 mm in *Notropis* sp.; 4.0 mm in sunfish; 5.5 mm in darters; 4.0 mm in herring; 4.5 mm in white perch; 6.0 mm in striped bass; 6.5 mm in mudminnow; and 6.0 mm in pirate perch. Fifty percent of all parasitized fish were 15.0 mm TL or less and 90% were 21.0 mm TL or less. Gut analysis of the fish examined in this study indicated that 10.2% of all *Morone* consumed copepods and 15.8% of all other fish did so. Copepods (all stages combined) contributed 13.8% and 74.7% of the striped bass diet in the River and Sound, respectively.

The difficulty in separating white perch from striped bass would mask any differences in parasitism prevalence by length class (those larvae between 8.0 and 15 mm were identified only as *Morone* sp.) so all *Morone* larvae were combined for length frequency analysis. The cumulative distribution of parasitized *Morone* larvae was similar to that of the cumulative total larvae examined as were the respective distributions of herring and darters (Figure 4). Thus the prevalence of parasitism would appear to be independent of fish length (in this size range) but in reality may not be so since the *Morone* larvae do not remain in the River but move into the Sound. The highest plerocercoid prevalence was found in the Sound. The distributions for *Notropis*, however, were dissimilar where the cumulative percentage of parasitized larvae increased faster than the cumulative percent examined in the 16 mm to 23 mm length classes. This indicates a greater prevalence of plerocercoid parasitism as *Notropis* length class increased. There were too few individuals examined in the remaining taxa to make length class/prevalence determinations. Plerocercoids in sunfish occurred within the 3 to 6 mm length range with 75% occurring in one fish. In menhaden, plerocercoids were distributed equally in the 30 to 42 mm length range (collected menhaden are generally larger than 25 mm in the Roanoke River). Only one yellow perch (17.5 mm), American eel (59.0 mm), Eastern mudminnow (6.5 mm), and pirate perch (6.0 mm) were parasitized by plerocercoids.

Twenty-three of the 33 stations sampled had parasitized fish. Ninety percent of those stations where no parasitized fish were collected were located in Albemarle Sound. The eleven

Table 2. Prevalence and intensity of pleroceroid and metacercaria parasitism in all fish taxa examined, 1982-1986, and 1988.

Taxa	N	Avg. T.L.	Range T.L.	pleroceroid Prevalence	Intensity	metacercaria Prevalence	Intensity
		all stations					
Striped bass	9598	6.1	3.0-26.5	0.4	1.3	0	0
White perch	2101	4.2	3.0-31.0	0.5	3.7	0	0
Morone sp.	1577	7.1	5.0-24.0	5.9	1.2	0.1	1
		stations 1,4,7,8,10,13,14,15					
Herring	4051	14.3	2.5-49.0	1.0	1.2	0	0
Notropis sp.	1248	18.2	4.5-38.5	8.6	4.5	0.5	1.7
Sunfish	271	5.8	3.0-26.0	1.1	5.3	0.4	3
Atl. menhaden	224	39.1	21.0-54.5	3.1	2.0	0	0
Darters	112	12.5	5.5-25.0	9.8	1.8	0	0
Carp	59	7.2	5.5-29.0	0	0	0	0
Brown bullhead	51	17.3	12.5-27.0	0	0	0	0
American eel	43	56.8	45.0-64.0	2.3	1.0	0	0
Yellow perch	30	18.7	10.0-31.0	3.3	1.0	0	0
Suckers	11	11.4	8.5-14.0	0	0	0	0
White catfish	7	17.3	16.5-18.0	0	0	0	0
Pirate perch	6	11.6	5.5-20.0	16.7	9.0	0	0
Atl. needlefish	6	17.3	11.5-19.5	0	0	0	0
E. mudminnow	3	31.4	6.5-34.0	33.3	3.0	0	0
Striped mullet	2	42.5	42.0-43.0	0	0	0	0
Hogchoker	2	26.2	24.0-28.5	0	0	0	0
Largemouth bass	1	27.0	-	0	0	0	0
Bay anchovy	1	45.0	-	0	0	0	0
Inl. silverside	1	23.0	-	0	0	0	0
Channel catfish	1	18.0	-	0	0	0	0
Mummichog	1	57.0	-	0	0	0	0
Enneacanthus sp.	1	29.0	-	0	0	0	0
Total	19408	9.0		1.6	2.5	0.04	1.8

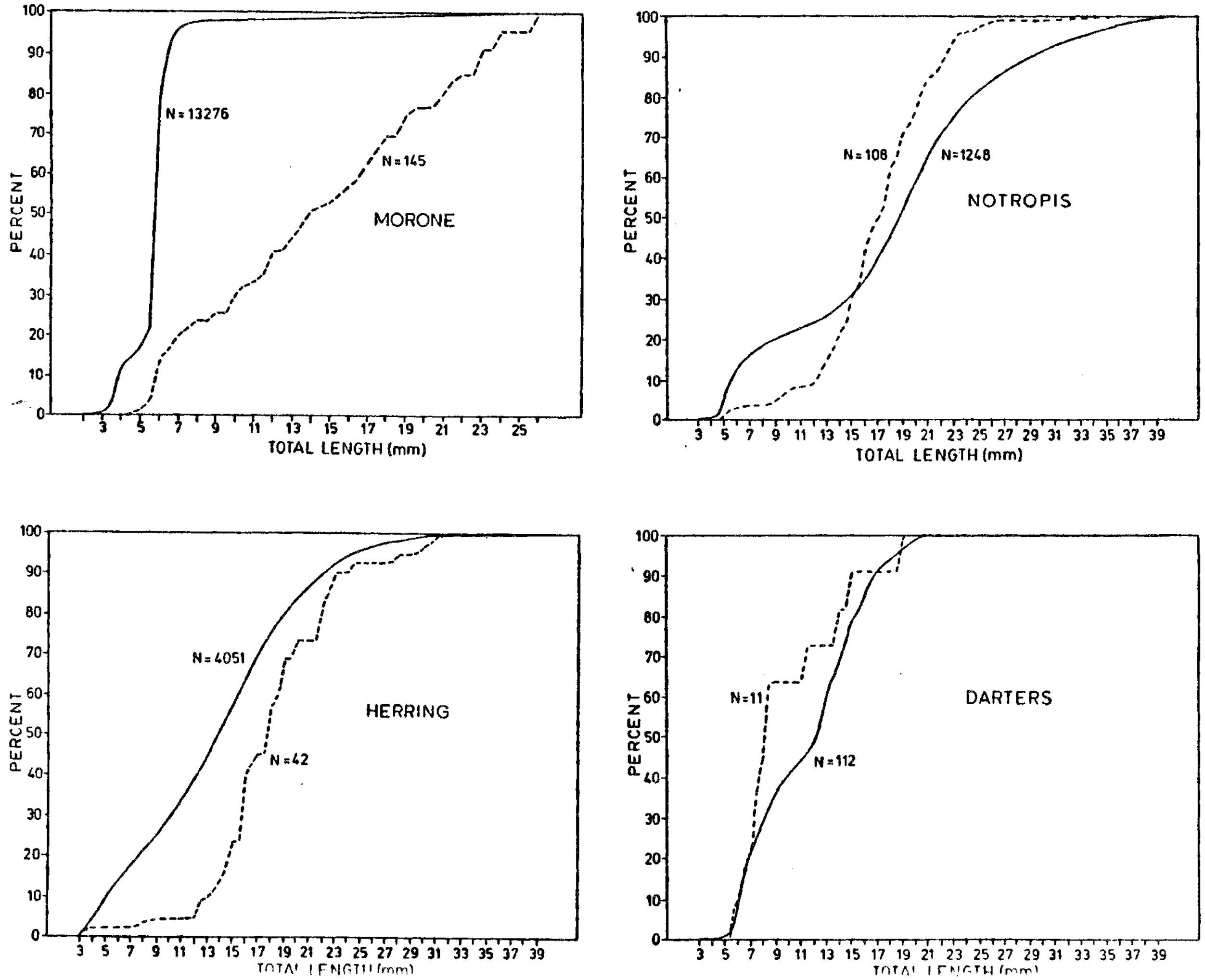

Figure 4. Cumulative percent distributions of fish examined (solid line) and fish parasitized by plerocercoids (dashed line).

stations at which 10 or more parasitized fish were collected were evenly distributed between River and Sound and between the Roanoke and the Cashie Rivers. The two stations in Middle River had fewer than 10 parasitized fish. Three stations in Albemarle Sound had the highest prevalence: Station 53 (38.7%), Station 18 (24.1%), and Station 21 (21.2%). Prevalence was much lower in the River ranging from a high of 8.1% at Station 4 to a low of 0.6% at Station 10. The average prevalence in the Roanoke (3.1%) was not significantly higher than the average in the Cashie (2.1%). There was no significant difference in prevalence between stations common to both groups of fish taxa (*Morone*; all other fish taxa). The highest prevalence of plerocercoid parasitism in the Sound did not occur at stations that had the highest overall copepod abundance. In the River, two of four (8, 11) stations with the highest prevalence also had the highest copepod abundance.

Infestation intensity by station did not follow the same trend as prevalence. Station 7 had the highest intensity (5.9) but the lowest prevalence. The opposite was true for Station 53. The stations (in ranked order) in the Cashie River (13, 8, 11) and those in Batchelor Bay (15, 14) remained the same in rank within each respective system for prevalence and intensity while those in the Roanoke River (7, 4, 10) and Albemarle Sound (21, 18, 53) reversed their respective rank order from prevalence to intensity by system. There was no significant difference in mean infestation intensity by River distributary. River stations with high intensity in each year did not have high copepod density for the same year except for Station 8 (highest in copepod density but third in intensity). This was also true of all stations in the Sound. Copepods (all stages) were an important component of the diet of all *Morone* examined and the percentage consumed increased from River stations (1-12; 8.6%) to Batchelor Bay stations (13-18; 52.9%) to Sound stations (20-55; 97.9%) reflecting the growth of the larvae.

All plerocercoid parasites found in *Morone*, menhaden, American eel, yellow perch, pirate perch, and mudminnow were located within the gut cavity. This was not true for *Notropis*, sunfish, darters or herring but the number of pleroceroids not in the gut cavity was low. The distribution of parasites was more diverse in *Notropis* than in any other taxa being found in tissue of the lower jaw (2.4%), tail (1.6%), head (0.6%), dorsal body (0.4%), and pelvic area (0.2%) as well as the gut cavity. The locations of plerocercoids in all parasitized taxa are summarized in Table 3.

Metacercaria

Metacercaria exhibited little internal development and were not identified. Metacercaria were spheroid and ranged in size from 0.12 mm to 0.72 mm across the long axis (X=0.29, SD=0.17, N=14) and from 0.08 mm to 0.72 mm across the short axis (X=0.19, SD=0.16, N=14). Metacercaria were found in the gut cavity (9, 64.3%), tail (4, 28.6%), and head (1, 7.1%).

Metacercaria were found only in *Morone* (one parasite), *Notropis* (10 parasites) and sunfish (3 parasites). Prevalence and intensity of infestation were less than that found for plerocercoids (Table 2). Parasitized fish ranged from 3.0 mm to 21.5 mm TL and 50% were less

Table 3. Percent occurrence of plerocercoid parasites in various body locations in larval fish, 1982-86 and 1988.

	Body location											
	Head		Dorsal body	Dorsal ffold	Tail	Pelvic	Gut cavity		Lower jaw	Ventral ffold	Total parasites	
Taxa	1-4	20-22	5-11	12-19	29-38	23	24-28	42-48	39-41	49-57	No.	%
Notropis	0.2	0.4	0.4		1.6	0.2	18.0	76.6	2.5		488	60.5
Morone							10.4	89.6			202	25.1
Herring							15.4	82.7	1.9		52	6.5
Darters						5.0	5.0	90.0			20	2.5
Sunfish		6.3				6.3	12.5	75.0			16	2.0
Atl. menhaden								100			14	1.7
Pirate perch								100			9	1.1
E. Mudminnow								100			3	0.4
Yellow perch								100			1	0.1
American eel							100				1	0.1
Percent	0.1	0.4	0.2	0	1.0	0.4	15.0	81.3	1.6	0	806	

than 15 mm TL.

Metacercaria were not found in large enough numbers to make any determination about prevalence by size class. The mean total length of all taxa parasitized by metacercaria was 14.1 mm (range: 3.0 to 21.5 mm). Four stations out of 26 sampled had fish larvae parasitized by metacercaria: Station 31 (1983); Station 7 and 8 (1984) and Station 4 and 7 (1985). Intensity was highest at Station 31 (3.0; one fish), equal at Stations 4 and 7 (1.7), and lowest at Station 8 (1.0).

Glochidia

Thirteen hooked glochidia were collected from five larval fish taxa from 1984 through 1986 and 1988. No glochidia were found in 1982 or 1983 (all samples were from Albemarle Sound). Striped bass and herring accounted for 69.3% of all glochidia attacks. Only one multiple attack was found: *Notropis* with a glochidium on each of the upper and lower jaw. Prevalence in all affected taxa was less than 0.5% (Table 4). Mussel collections in the present study yielded two genera of Anodontinae, *Anadonta* (one empty shell) and *Alasmidonta* (one empty, one alive) that could be the source of the collected glochidia. Other mussel genera found were *Lampsilis* (Lampsilinae, one empty shell), and numerous live specimens of *Rangia cuneata*, *Sphaerium* sp., and *Corbicula fluminea*.

Glochidia were most prevalent in those larvae less than 7.0 mm TL (69%) and the mean total length of all affected taxa was 7.8 mm. The low number of attacks prevents making any specific analysis on prevalence by station but in general, mean prevalence was higher in the Cashie River (23.1%, Stations 8 and 13) than in the Roanoke River (15.4%, Stations 1 and 10), Middle River (15.4%, Station 6), or Albemarle Sound (7.7%, Station 15). All glochidia attacks found in this study occurred in the head region divided between brain area (30.8%), lower jaw (30.8%), upper jaw (23.1%), and opercle (15.4%).

Mesocyclops edax

Six larval fish taxa were attacked by *Mesocyclops edax* in the samples examined from 1986 and 1988 (Table 5). Striped bass was the primary prey accounting for 67% (N=54) of the larvae attacked, including five multiple attacks of two copepods each. Herring were second in attacks (17.3%, N=14), followed by white perch (7.4%, N=6), sunfish (4.9%, N=4), *Morone* sp. (2.5%, N=2), and suckers (1.2%, N=1). White perch and sunfish also had multiple attacks. The mean total length of all fish attacked was 6.2 mm (N=81, SD=2.5, range 3.0-18.5 mm). Attacks were directed at the gut cavity (or yolksac, 22.7%), tail (20.4%), lower jaw (13.6%) and head (10.2%). The remainder (33%) was distributed over the body.

In 1986, 52.6% of the attacks occurred at Station 12, more than twice the rate at any other station. Forty-two percent of the attacks occurred within a single sample and 65.7% were found in two samples. In 1988, 38% of the attacks occurred at Station 11 and 30% at Station 15. Nearly 90% of the attacks were found in samples of two dates. Stations 6, 11, 12 and 13

Table 4. Summary of larval fish examined for glochidia, 1982-1986, and 19

Taxal	N	Mean TL	Range	Number of glochidia	Prevalence	Intensity
			all stations			
Striped bass	9598	6.1	3.0-25.0	5	0.05	1.0
Morone sp.	1576	7.1	5.0-24.0	0	0	0
White perch	1574	4.1	2.5-25.0	1	0.06	1.0
			stations 1,4,7,8,10,13,14,15			
Herring	5384	12.3	2.5-25.0	4	0.07	1.0
Notropis sp.	1803	11.5	4.5-25.0	2	0.11	1.0
Sunfish	381	5.9	3.0-24.0	1	0.26	1.0
Darters	183	12.6	4.5-25.0	0	0	0
Carp	73	6.9	5.5- 8.5	0	0	0
Brown bullhead	61	16.8	12.0-23.0	0	0	0
Yellow perch	49	16.0	6.5-25.0	0	0	0
Suckers	47	14.4	8.5-17.5	0	0	0
Pirate perch	12	9.0	5.5-20.0	0	0	0
Atl. silverside	11	7.7	5.0-23.0	0	0	0
White catfish	8	17.6	16.5-20.0	0	0	0
Atl. needlefish	7	17.0	11.5-19.5	0	0	0
Channel catfish	5	17.3	16.0-18.0	0	0	0
E. mudminnow	1	6.5	-	0	0	0
	20773	8.2		13	0.06	1.0

Table 5. Summary of Mesocyclops edax attacks on larval fish in 1986 and 1988. Fish examined come from all stations sampled.

Taxa	N	mean TL	range	Number of attacks 1986	1988	total	prevalence	intensity
Striped bass	18229	5.9	3.0-26.5	22	37	59	0.3	1.1
Herring	12434	6.7	2.5-38.0	8	6	14	0.1	1.0
Notropis sp.	4307	6.4	3.5-30.0	0	0	0	0	0
White perch	4285	3.8	2.0-26.0	7	0	7	0.2	1.2
Darters	657	7.6	4.0-28.0	0	0	0	0.8	0
Sunfish	621	5.6	4.5- 9.0	1	4	5	1.0	1.0
Morone sp.	196	10.2	4.5-19.0	0	2	2	0	1.0
Carp	107	6.8	5.0- 8.0	0	0	0	1.1	0
Suckers	93	15.2	10.0-17.5	0	1	1	0	1.0
Yellow perch	32	15.5	7.0-40.0	0	0	0	0	0
Atl. silverside	32	6.0	4.0-10.5	0	0	0	0	0
Brown bullhead	30	15.7	12.0-22.0	0	0	0	0	0
Pirate perch	23	7.0	6.0- 8.0	0	0	0	0	0
Channel catfish	13	16.9	14.0-19.5	0	0	0	0	0
Total	41059	6.1		38	50	88	0.2	1.1

accounted for 81% of the attacks over both years.

Prevalence of *M. edax* attacks was highest in suckers (1.1%) followed by *Morone* (1.0%) and sunfish (0.8%). Intensity of infestation was higher in striped bass (1.2) and white perch (1.1) but there was no significant difference in prevalence or intensity between these taxa. Overall prevalence was less than 0.5% and overall intensity was 1.1 (Table 5). Fish larvae less than 8.0 mm TL accounted for 95% of the recorded attacks by *M. edax*. The other attacked larvae averaged 16.2 mm (range: 14.0 to 18.5 mm). Two genera of parasitic copepods were collected (*Ergasilus* and *Argulus*) and one predatory cladoceran (*Leptodora*) but there was no evidence of parasitism or predation by these genera.

DISCUSSION

Plerocercoids parasitize copepods as a primary host and become established in larval fish after the fish have ingested the infested copepods or an infested fish. This method of transmission allows the parasite to become established in fish larvae of relatively small size. Although the limited development of the plerocercoids found in this study precludes identification, it is reasonable to assume that the plerocercoid-parasitized fish became so through the ingestion of infested copepods. This is supported by the fact that no fish were found to be parasitized by plerocercoids that had not begun feeding and by the relatively high percentage of copepods in larval fish diets.

Metacercaria do not follow the same strategy as plerocercoids in that this parasite actively penetrates the host tissue, thus the host does not need to have feeding capability to become infested. The only requirement is physical contact with a suitable fish host. The life cycle is completed when the infested fish is consumed by the appropriate final host: fish-eating bird, mammal, fish or reptile (Hoffman 1967).

The initial attachment of glochidia to its host is random, relying on physical contact to stimulate closure of the valves (Pennak 1978). The presence of glochidia on a fish, however, does not necessarily indicate that the fish is a proper host as glochidia of many mussel species are host-specific (Neves et al. 1985). The glochidia that become attached to an unsuitable host may release it voluntarily or be sloughed off by the host (Weaver et al. 1991).

In Chesapeake Bay, Paperna and Zwerner (1976) found young-of-year striped bass parasitized by many parasites, among which were two types (designated A and B) of unidentified proteocephalid plerocercoids as well as *Scolex pleuronectis* and a trypanorhynchoid plerocercoid. White perch young-of-year were also found to harbor the type A proteocephalid plerocercoid and glochidia. These parasites were found in similar body locations as that found in larval striped bass and white perch in the present study. These authors found that the presence of encapsulated helminth larvae caused lesions in 39% of the striped bass at four to five months of age. These lesions were also common in white perch which led to extensive fibrosis of the visceral organs. None of these traits were detected in the present study but the fish examined had not progressed beyond a maximum of two months of age and the majority were about two weeks old. This amount of time may not be enough for lesions to be detectable.

Fish larvae also would be affected by competition with the parasite for nutrients which would become more severe as intensity increases. In larvae such as white perch, sunfish, herring, and *Notropis* (which are relatively thin for their length) the percent of theoretical body volume occupied by the observed plerocercoids and metacercaria ranged from 9% in 5.0 mm TL larvae to less than 1.0% in 8.0 mm TL larvae. Thus the smaller larvae carry a much greater burden per parasite than even slightly larger larvae. The volume would increase as intensity increases, reaching an extreme in greatly infested fish, e.g. the 13 mm TL *Notropis* which harbored more than 90 plerocercoids or 88% of the theoretical host body volume. Larger, more robust larvae such as striped bass, darters, and yellow perch may be less affected in body volume by single parasite infestations. Atlantic menhaden would carry the least burden because of their relatively large size when they first encounter these parasites.

Proteocephalid plerocercoids have been found in other larval fish taxa in marine environments [spot, gulf menhaden, Atlantic croaker (Govoni 1983)] and in freshwater [bluegill, largemouth bass (Fischer and Kelso 1990)] in similar size ranges as reported in the present study. However, their studies did not show as high a prevalence among as many diferent taxa as in the present study.

Glochidia were listed as frequent on juvenile fish in Albemarle Sound (Mozley 1984) and have been found on juveniles of several fish species elsewhere (Paperna and Zwerner 1976; Moles 1983; Mozley 1984; Cunjak and McGladdery 1991). In the present study, glochidia were found on much smaller larvae (X = 7.8 mm) than those reported by Fischer and Kelso (1990) (>14 mm) but their presence on these larvae in itself does not show host compatibility (Neves et al. 1985) as the host may slough off glochidia after a period of time. Little is known about the mussel species inhabiting the lower Roanoke River system (Shelley 1987) and there may be additional species in this area that were not found in this study.

Predatory copepods are more limited in the size selection of their prey, concentrating, for the most part, on smaller, less mobile fish larvae (Fabian 1960, Smith and Kernehan 1981, Hartig et al. 1982, Hartig and Jude 1984). In the above studies, the approximate average of attacked fish larvae was less than 8 mm, similar to the size distribution found in this study. In some cases, however, larger larvae may be attacked (21-25 mm; Hartig et al. 1982; 10-14 mm; Hartig and Jude 1984; 14 to 18.5 mm; present study). Hartig and Jude (1984) believed this to be in contrast with the apparent findings of Kerfoot (1977) in that *Diacyclops bicuspidatus* preferred to avoid larger prey (*Bosmina*). It is more likely that the avoidance of *Bosmina* by *D. bicuspidatus* is in response to size as well as the increased potential for prey escape (Kerfoot 1975) caused by the difficulty in handling larger prey that have a defensive carapace: larval fish are soft-bodied and their only defense would be increased swimming speed and increases in strength (and increases in hardness of surface body tissue) with increases in size. The data of Hartig et al. (1982), Hartig and Jude (1984), and that of the present study clearly show that cyclopoid copepods will attack prey much larger than themselves (up to 15X larger) but successful attacks may be determined by the relative fitness of the prey. These larger fish may have been injured or were in poor condition and therefore more vulnerable to attack. This would account for the relatively low incidence of attack on larger fish larvae.

Williamson (1980) has found that the type of motion by potential prey through the water influences the probability of attack by *Mesocyclops edax*: smooth movement of rotifers and ciliates reduced the attack probability but the jerky motion of the cladoceran *Bosmina* increased the attack probability. After an attack,*Bosmina* will fold the antennae flush with the carapace and passively sink in the water column; this lack of movement was apparently insufficient to stimulate the mechanoreceptors of the attacking copepod and the cladoceran would escape (Kerfoot 1977). Rapid vibration of the tail by fish larvae, particularly recently-hatched larvae, would increase their probability of being attacked (Lillelund and Lasker 1971) by the production of compression waves that would be detected by the copepod.

Spatial and temporal proximity were the key factors in copepod attacks on larval fish examined by Hartig et al. (1982) and Hartig and Jude (1984) and attacks were more likely in areas of high abundance of either predator or prey. The data in the present study indicate that spatial and temporal proximity may be more important than densities as several of the most prevalent attacks occurred when neither predator nor prey were high in relative density. There is a possibility that some of the recorded attacks may be due to the spatial proximity of copepods and larval fish within the collecting gear. This would not be true of those copepods that showed evidence of feeding on larvae. The resolution of this becomes more complex in light of the findings of Lillelund and Lasker (1971) where marine copepods dropped larvae upon addition of 3% formaldehyde.

Hartig et al. (1982) concluded that cyclopoid predation was a significant mortality factor of larval fish, in contrast to Smith and Kernehan (1981), and stated that their estimates of predation might be low because of the addition of formaldehyde. Predation estimates in the present study might also be low because of formaldehyde but also because of the sinking behavior of *Mesocyclops* when handling large prey (Williamson 1980). However, if additional attacks were recorded as a result of collection methods, then the estimate of predation may be too high.

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