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FOOD AND FEEDING OF YOUNG FINFISH SPECIES IN THE LOWER ROANOKE RIVER, BATCHELOR BAY, AND WESTERN ALBEMARLE SOUND, NORTH CAROLINA, 1982-1988

Volume I - Text

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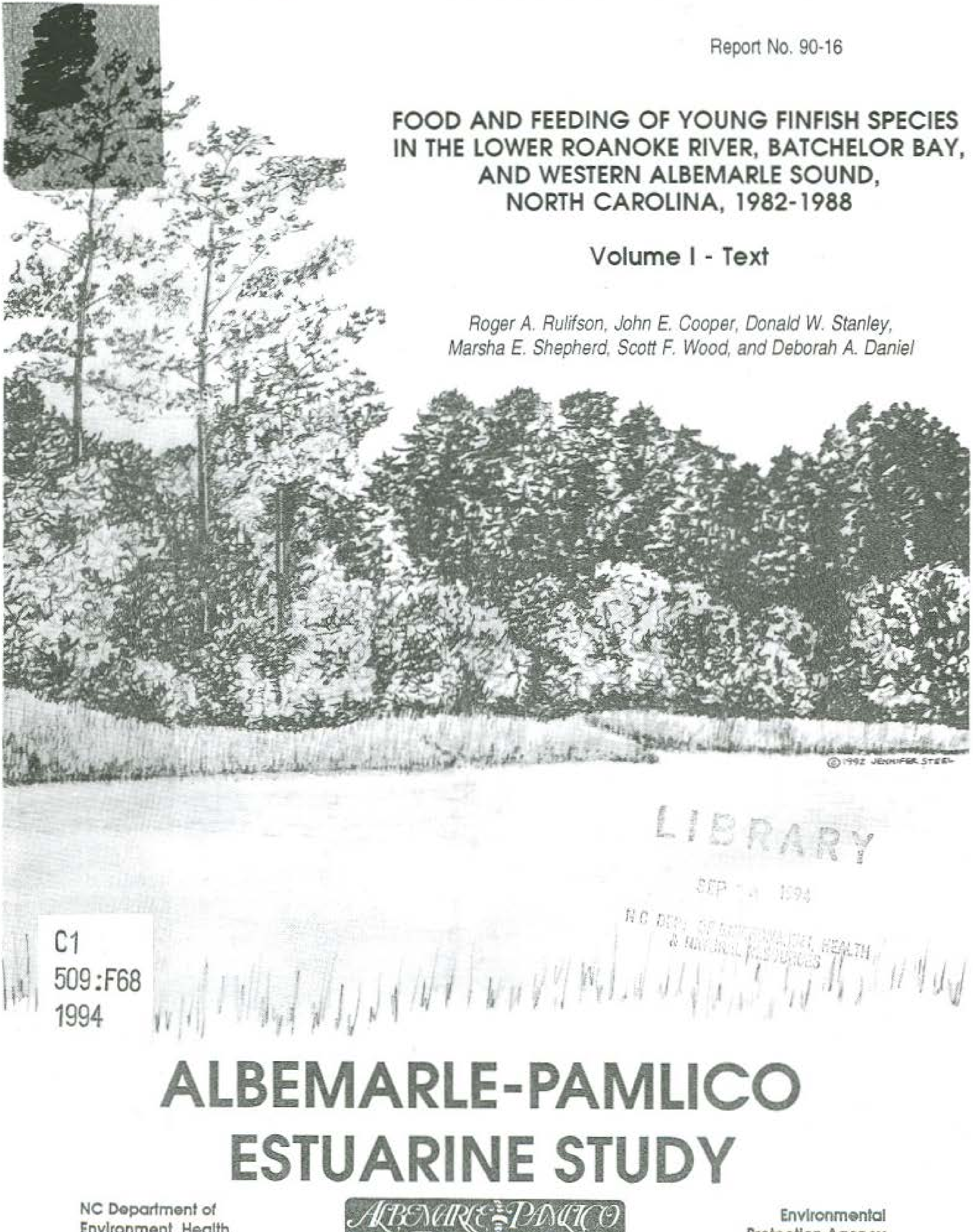

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ALBEMARLE-PAMLICO ESTUARINE STUDY

NC Department of
Environment, Health,
and Natural Resources

Environmental
Protection Agency
National Estuary Program

Food and Feeding of Young Finfish Species in the Lower Roanoke River, Batchelor Bay, and Western Albemarle Sound, North Carolina, 1982-1988

Volume I - Text

By

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EXECUTIVE SUMMARY

The goals of the study were to characterize the food web for larval striped bass and other young finfish species in the lower Roanoke River and western Albemarle Sound, North Carolina, and to ascertain if food chain interruption may be a factor contributing to poor recruitment. Striped bass recruitment to the year class forming in the nursery grounds of western Albemarle Sound has been poor relative to the numbers of eggs spawned by adult fish in the Roanoke River each year. Therefore, abnormally high mortality is occurring between egg hatch and juvenile recruitment. An inadequate food supply would result in starvation of the larvae. An inadequate supply can be the result of low numbers of prey items, inaccessibility to prey by fish larvae due to prey size or quickness, or both factors. If striped bass larvae in the Roanoke-Albemarle system are food limited, then an examination of co-habiting young finfish species should indicate whether the food limitation is quantity, quality, or both. Those species that have diet overlap with striped bass may show greater success at feeding on preferred prey of striped bass, suggesting that striped bass are outcompeted for food resources. On the other hand, those same finfish species may show a poor feeding rate, similar to striped bass, suggesting that young finfish in the system are food limited by quantity of prey. We combined data sets on water quality, primary productivity, zooplankton, larval abundance, and larval food habits collected in the springs of 1982-1986 and 1988 to provide information spanning six years of varying seasonal and river flow patterns. The year 1987 was a flood year in which too few striped bass larvae were collected to perform food habit analyses. Collection sites were the lower Roanoke River, delta (Thoroughfare, Cashie, Middle, Eastmost, and Roanoke rivers), Batchelor Bay, and western Albemarle Sound.

River Flow. Regulation of instream flow by the last three dams in the watershed (Kerr, Gaston, and Roanoke Rapids), combined with annual variability in rainfall, resulted in river discharge patterns for all study years atypical of the historical pattern. The historical seasonal pattern of river flow is one in which spring rains result in higher river discharge in March and April, followed by moderation in May and lower flows in June. Flood years were 1983, 1984 and 1987; highest flows were in April through mid-May. Spring 1982 river flows were lowest in April and continued to increase through May with peak discharge during mid- through late June. Drought years were 1985 and 1986; in both years instream flows were increased briefly by reservoir releases to the minimums required for striped bass spawning. Spring 1988 river flows were regulated by the U.S. Army Corps of Engineers and Virginia Power using instream flow guidelines under development at the time by the Roanoke River Water Flow Committee.

Water Quality. Spring water temperature patterns 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 higher in Batchelor Bay and western Albemarle Sound than in the lower Roanoke River and delta at the same time. Dissolved oxygen values in the study area were above 4 mg/L every spring, with notable exceptions during high flow periods in 1987. Surface water pH values were acidic much of the time in 1986, with an observed low of 6.0 in late May. Acidic conditions also were evident in 1987, but in 1988 pH values remained at 7.0 or above. Salinity values ranged from 0.0 to 0.4 ppt indicating that the lower River and western Albemarle Sound are oligohaline. Patterns of short-term fluctuations in salinity were similar to what might be expected with an internal seiche. Nutrient and heavy metals analyses indicate that concentrations are affected by river flow. Upstream, the average values for solids, turbidity, nitrogen (except for NO_2/NO_3-N) and phosphorus species, and metals were higher during moderate and stable flows. In the delta, several parameters including color, TKN, NH_3-N, SO_4, Ca, Na, SO_4, and alkalinity were higher in the lower Roanoke River downstream of Plymouth, NC compared to the Cashie River. Carbon was higher in the Cashie River.

Primary Production. Most of the algae are small species that should be usable as food for grazing zooplankton in the river; concentrations are higher than required for sustaining the zooplankton community found in the study area. The Roanoke phytoplankton is dominated by green algae and diatoms, a community resembling that of a lake more than an estuarine environment. Blue-green algae, usually considered undesirable as food for zooplankton, were not present in significant quantities in the spring. Chlorophyll *a* concentrations showed a clear inverse relationship with Roanoke River flow; i.e., low flow conditions resulted in higher chlorophyll *a* concentrations.

Zooplankton Production. The zooplankton assemblage, resembling that of a freshwater system, was in low abundance within the study area at concentrations much lower than other river systems supporting striped bass populations. Since zooplankton abundance in this system is not phytoplankton limited, then environmental factors must play a role in maintaining low zooplankton abundance. Results indicate that daily river flow, as well as seasonal flow patterns, change the zooplankton communities of the study area. 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. Zooplankton abundance is patchy, with highest concentrations in the delta, especially the Cashie and Middle rivers. In Batchelor Bay, highest concentrations were along the western shore, and western Sound concentrations were highest along the north shore near Edenton Bay. River zooplankton were dominated by copepods (mainly cyclopoids) and cladocerans (mainly *Bosmina* and *Daphnia*). Batchelor Bay was a region of zooplankton community transition; copepods and cladocerans still dominated numerically but the predatory cladoceran *Leptodora* and gammarid amphipods were more abundant. Western Albemarle Sound zooplankton were mostly copepods (75% of all individuals), with cladocerans (primarily *Leptodora*) second in abundance.

Ichthyoplankton Species Composition. Thirty-four species or species groups of young finfishes were found in the study area. The most abundant finfishes (highest to lowest) included Clupeidae (e.g., alewife, blueback herring, American shad, gizzard shad), striped bass, white perch, minnows (genus *Notropis*), Atlantic menhaden, sunfishes (Centrarchidae), and darters (Percidae). Occasional ichthyoplankton species included common carp, brown bullhead, American eel, suckers (*Catastomus*), pirate perch, yellow perch, inland silverside, channel catfish, Atlantic needlefish, white catfish, tessellated darter, eastern mudminnow, bay anchovy, longnose gar, redfin pickerel, largemouth bass, striped anchovy, chain pickerel, hogchoker, swamp darter, and Atlantic croaker.

Feeding Success of Young Finfishes. Striped bass larvae exhibited poor feeding success not observed in the other 25 co-habiting species examined. Only one-fourth of larval striped bass contained prey. In contrast, prey was found in stomachs of over 80% of the white perch larvae, the most closely-related species and possessing a similar life history strategy. Striped bass appear to be competing directly with other larval fish species for desirable zooplankton prey, primarily *Bosmina*, rotifers, and copepodite copepods. The most abundant members of the zooplankton community -- adult cladocerans and copepods -- are not being utilized as food to the fullest potential.

Possible Causes of Poor Feeding Success. The low percentage of striped bass with prey in stomachs may be related to fluctuating river flows that transport larvae away from areas of zooplankton abundance, creating a mismatch between striped bass and zooplankton abundances. Preferred food items would be in abundance too low for striped bass larvae to feed effectively. Because of this mismatch, striped bass mortality is abnormally high. This results in poor recruitment, thus contributing to poor year class strength. This mismatch problem is observed in other river systems supporting striped bass and other species; both river flow and water temperature are thought to be major factors controlling the match/mismatch phenomenon. Low zooplankton concentrations observed in the Roanoke system do not mean that successful year classes are not possible, because in years of high larval fish production more young will survive regardless of the 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, the anadromous 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. 1982). 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 at River Mile (RM) 120 and Weldon (RM 130), North Carolina, from mid-April through June (Rulifson et al. 1993). 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 (Hassler reports, Rulifson reports). After hatching, the larvae continue downstream through the Roanoke River delta and into western Albemarle Sound to the historical nursery areas (Rulifson et al. 1988, 1992a, 1992b).

Other finfish species utilizing Albemarle Sound and the Roanoke River represent a diverse collection of life history strategies. Anadromous species besides striped bass include the American shad (*Alosa sapidissima*), blueback herring (*A. aestivalis*), alewife (*A. pseudoharengus*), hickory shad (*A. mediocris*), and Atlantic sturgeon (*Acipenser oxyrhynchus*). The shortnose sturgeon (*A. brevirostrum*) is believed to be present though uncommon (Laney et al. 1989). The semi-anadromous white perch (*Morone americana*) is abundant and a close relative of striped bass. The only catadromous species is the American eel (*Anguilla rostrata*). Several of the anadromous species (e.g., striped bass, white perch, American shad) require freshwater discharge from rivers and streams at a rate adequate to suspend eggs and larvae within the water column, and to transport the young to nursery grounds. Others (e.g., sturgeons and blueback herring) require flowing waters to bathe the adhesive eggs until hatching; larvae are then transported downstream to the nursery grounds. Coastal estuarine species include the Atlantic menhaden (*Brevoortia tyrannus*) and gizzard shad (*Dorosoma cepedianum*), both of which utilize the oligohaline and brackish nursery areas of Albemarle Sound. Several catfish species (*Ictaluridae*) also utilize these habitats. The remaining species are resident freshwater fishes, the young of which are found in shallow vegetated areas of the rivers and streams. Most of these species are in one of the following groups: minnows (Cyprinidae), suckers (Catostomidae), catfishes (Ictaluridae), sunfishes (Centrarchidae), and darters (Percidae) (Table 1).

From the mid-1970s through the 1980s, the striped bass fishery in Albemarle Sound suffered from declines in harvest. A number of environmental factors and overharvest have been hypothesized as contributing to the decline. Until the late 1980s, a strong year class of Roanoke striped bass had not been observed since 1970, and no significant year classes were produced since 1976 (Hassler et al. 1981; USDOI and USDOC 1985). Only recently have environmental restoration and regulatory efforts been successful in producing relatively strong year classes of striped bass in 1988 and 1989 (Rulifson and Manooch 1990a, 1993; Nelson 1993; Henry and

Taylor 1993). At the same time, young-of-year recruitment for other finfish species exhibited no real patterns during the 1980s (Henry and Manooch 1993). The 1988 and 1989 striped bass year classes are now protected by a myriad of regulations and subject to commercial and recreational harvest quotas until the striped bass decline is stabilized (Henry 1993).

In spite of the seemingly strong year classes of striped bass in 1988 and 1989, there remains an abnormally high level of early life stage mortality, particularly after eggs hatch and before recruitment of young-of-the-year is completed on the nursery grounds of western Albemarle Sound (Rulifson et al. 1993). Starvation has been hypothesized as one of the principal causes of larval Roanoke striped bass mortality (Rulifson 1984a; Rulifson and Stanley 1985; Rulifson et al. 1986a, 1986b), and was 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, also has been hypothesized (Rulifson 1984a).

Zooplankton surveys conducted in western Albemarle Sound in 1982 and 1983 (Rulifson 1984a), and in the lower portions of the Roanoke watershed from 1984 through 1991 (Rulifson et al. 1992a, 1992b), 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).

If striped bass are food limited in this system, then examination of early life stages of other co-habiting finfish species should indicate whether the limitation is quantity, quality, or both. Those species that have diet overlap with striped bass may show greater success at feeding on preferred prey of striped bass, suggesting that striped bass are being outcompeted for food resources. On the other hand, those same finfish species may show a poor feeding rate, similar to striped bass, suggesting that young finfish in this system are food limited by quantity.

The goals of the study described herein were to characterize the food web for larval striped bass and other young finfish species in the lower Roanoke River and western Albemarle Sound, North Carolina, and to ascertain if food chain interruption may be a factor contributing to poor recruitment. The objectives of this study were: 1) to determine the relative abundance and distribution of major larval fish species in the lower Roanoke River and western Albemarle Sound; 2) to determine the type and number of prey organisms ingested by these young fish species; 3) to determine the relationships existing between larval fishes and zooplankton; and 4) to determine differences in feeding success between striped bass larvae and other larval fishes. Results of portions of these aspects, especially feeding success of larval striped bass and white perch, were documented by Rulifson (1984a, 1984b), Rulifson and Stanley (1985), Rulifson et al. (1986a, 1986b, 1988), Manooch and Rulifson (1989), and Rulifson and Manooch (1990a, 1990b, 1991, 1993). Large portions of the text described herein, especially the site description and description of river flow, water quality, and zooplankton, were compiled and written originally for a long-term study (Rulifson et al. 1992a, 199b), but are reiterated to provide a detailed context for interpretation of the new information presented in the current study. One of the most important environmental components is river flow. At the present time, U.S. Geological Survey (USGS) personnel are in the process of describing flow patterns of the lower Roanoke River and western Albemarle Sound using mathematical models (Bales et al. 1993). Their studies are not complete at this time, so we have used the flow records from the USGS gage at Roanoke Rapids. Complete data sets for water quality, chlorophyll, phytoplankton, zooplankton, and larval fish are presented in Volume II of this report.

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 constructed near the North Carolina-Virginia border for hydroelectric power and flood control. The most upstream of these impoundments is John H. Kerr Reservoir at 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 now spawn in several tributary rivers. 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. The Federal Energy Regulatory Commission (FERC) license for both Gaston and Roanoke Rapids facilities expires in 2001, so at the present time the company is conducting pre-application studies of the area. Of the three 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 cubic feet per second (cfs) at the mouth (252 m^3/second, or 0.01 m^3/second/km^2), the Roanoke River has the second greatest outflow of any North Carolina 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 lower Roanoke River (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, the 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 (Riggs et al. 1993).

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) (Mulligan et al. 1993). 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 2). 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).

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 dates and stations selected for sampling changed each year depending on striped bass spawning activity, local weather patterns, and results from the previous year. Twenty-nine fixed sampling sites in the lower river, delta, and western Albemarle Sound have been sampled at various times since 1984 (Figure 2). Not all stations were sampled in all years. Table 3 provides a description of each location and the years for which each station was sampled. Ichthyoplankton and zooplankton also were collected from western Albemarle Sound in 1982 and 1983. These samples were collected by the NC Division of Marine Fisheries (DMF) as baseline information for the larger (1984-1991) study. Where possible, the 1982 and 1983 information is used in several analyses.

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 3) 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. A stern-mounted goalpost structure of the same design was used for net deployment.

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. 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 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 visible 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, 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 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 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 acidiodine 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, all of which were removed, prior to processing the zooplankton 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 twice. Data were reported as the mean number of individuals per m^3 for each taxonomic group. The zooplankton taxa collected and their relationships are presented in Table 4.

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) were 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 a Tucker trawl towed 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 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 from 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 for enumeration and identification from each ichthyoplankton sample. *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 of development was classified as: (1) larvae possessing yolk; (2) larvae with no yolk, the oil globule may or may not have been present and the fish was most likely capable of feeding; and (3) juveniles, identified by the presence of adult body shape, full complement of fin rays, and scales.

Young of fish species other than *Morone* were subsampled from selected stations for a comparison of food habits. Sites selected for this comparison were Stations 1 and 4 (Upriver), Stations 7 and 10 (Downriver), Station 8 (Cashie River), Stations 13-15 (Batchelor Bay), and Stations 21 and 22 (western Albemarle Sound). Four years of data were used in the comparisons: 1984 (flood year), 1985 and 1986 (drought years), and 1988 (moderate flows). Samples from 1987 were not used because the extreme flood conditions resulted in few larvae collected. All fish were removed from these samples, identified to the lowest taxon practical, and enumerated.

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.

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. Those fish containing prey in stomachs were categorized as feeding successfully.

Feeding habits of the other fish species were determined by examining the gut contents of fish subsampled from the entire sample. Most samples contained less than 300 larvae, but some had nearly 2,000 larvae. For each sample, a maximum of 50 fish of the most abundant species were measured and examined for gut contents in the same manner as for *Morone*. The exact number of larvae examined for each species was dependent on the percent contribution of the species group to the total sample. For example, if white perch larvae represented 60% of all fish in a sample, then 30 of the 50 larvae examined from the sample were white perch. In addition, other species occasionally present in samples were examined (usually 3-5 fish) so that no more than approximately 55 fish per sample were processed for gut contents.

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. 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. 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 (1994). Unit values (quarter-hour) are used to determine an average daily discharge measured in 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

Data management and statistical analyses were performed using the Statistical Analysis System (SAS Institute 1985) on the East Carolina University mainframe computer. Data sets included water quality, phytoplankton, chlorophyll *a*, zooplankton, and larval fish. Stepwise procedures were used to identify variables that were statistically 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.

RESULTS

Water Quality

River Flow. The mean instream flow of the lower Roanoke River in 1982, measured at Roanoke Rapids, was lower (7,613 cfs) than the long-term mean annual flow (8,120±8,622 cfs). The average river discharge for the April-June period was 8,779 cfs (Table 5), a value very close to the long-term seasonal average of 8,994 cfs. However, the spring 1982 flow pattern was different than the normal situation of higher flows in March and April followed by low flows in June. Nearly 21% of the average flows for April-June were <3,000 cfs, and all occurred in April (Figure 3). Over 35% of the daily flows were above 10,000 cfs (Table 5), primarily at the end of the spawning season. This discharge pattern was the result of lower than normal rainfall in May, followed by almost one inch more of rainfall than normal in June (Table 6).

The instream flow pattern of spring 1983 was opposite that of 1982 (Figure 3), with average flows (16,278 cfs) nearly double the long-term average (Table 5). Rainfall in April 1983 was 5.99 inches, the highest amount recorded for the month since 1952 (Table 6). Rainfall for May and June were lower than normal. Over 41% of the April-June daily flows were above 20,000 cfs; reservoir discharge did not drop below 20,000 cfs until late May. Instream flow throughout June was erratic and higher than normal.

Instream flows for calendar year 1984 averaged 10,091 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), 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). These instream flow recommendations were commonly referred to as the Q_1-Q_3 flow regime, based on the historical 25% average low flows (Q_1) and the historical 75% average high flows (Q_3). The flow criteria are depicted in Figure 3. Only 4.4% of the days within the April-June period had mean instream flow values $\geq$10,000 cfs (Table 5).

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 and 1988 (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 (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 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.

Surface Water pH. Patterns of surface water pH were different for each year. For 1984 and 1985, information on pH was collected by a color method, so data quality was limited. 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 1988, 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. 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.

Special Water Quality Studies. Special water quality studies were conducted in 1988 with the cooperation of Weyerhaeuser Company and East Carolina University (Rulifson et al. 1990); results of these studies are summarized in this section. Various aspects of water quality upstream (River Mile 105 in 1988) were compared to that collected within the Roanoke River delta (Stations 5, 6, 7, 8, 10) (Figure 2).

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). 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: 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.

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.

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 pertinent literature presents chlorophyll *a*, density, and biomass data for many freshwater and estuarine systems.

Chlorophyll *a* levels are generally less than 10 µg/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 8, Appendix Table C-5). Station averages were mostly around 6-7 µg/L.

In 1984 (higher flow year), chlorophyll *a* concentrations were lower on average than the drought years of 1985 and 1986 (Figure 8). Concentrations of chlorophyll were slightly higher on average (Stations 1-12) than in Bachelor Bay (Stations 13-16) (Figure 8). 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 8), 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).

In 1988, river chlorophyll *a* values were higher on average than Bay values. With the exception of initial high readings on the first sampling date, concentrations of chlorophyll *a* increased steadily from April into May as expected with moderate stable river flows (Figure 8).

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 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 9). 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 9). 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 9). 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 2,000 µg wet weight/L. Over time the average biomass for all stations declined from 1,500-3,400 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 10).

Cell densities and biomass for the various algal taxonomic groups were 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. 1986a).

Linear regression indicated no statistically significant correlation ($r^2=0.05$) between Roanoke chlorophyll *a* concentration and phytoplankton biomass.

Zooplankton

The patterns of zooplankton abundance and distribution in the lower Roanoke River, Batchelor Bay, and western Albemarle Sound are different each year (Figure 11). 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 11) 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).

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 (Stations 8 and 11, Figure 2). 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 (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. Zooplankton in River samples was dominated by copepods, mainly cyclopoids, and cladocerans, primarily *Bosmina* and *Daphnia* (Table 9). Batchelor Bay is a region of transition for the zooplankton community. Copepods and cladocerans still dominate the community (Table 10). *Leptodora*, a predatory cladoceran seldom observed in River samples, was in greater abundance in Bay samples. Gammarid amphipods become an important part of the zooplankton community in Batchelor Bay, ranging up to 7% of all zooplankton in numerical abundance in 1988. In the western Sound, copepods dominate the zooplankton community, representing over 75% of the total individuals present (Table 11). The remainder of the community was mostly cladocerans, with *Leptodora* representing the dominant genus of the group (Table 11).

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. The major taxa, as described above, were still present but the rare organisms disappeared from daytime samples.

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 12, Table 13). Mean wet weight biomass for each species was then estimated (Table 14) and its relationship to zooplankton body length determined (Table 15). 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 and delta was dominated by cladocerans, which contributed 40-86% of the seasonal wet weight estimate (Table 16). Cladoceran biomass contributed more to total biomass in high flow years (1984, 65%; 1987, 86.2%). Copepods represented the second highest biomass, but their percent contribution to zooplankton biomass estimates was lower in high flow years (e.g. 1984, 10%; 1987, 3%).

Patterns of zooplankton biomass in Batchelor Bay were similar to that exhibited in the River with regard to seasonal water flows, and amphipods were important biomass contributors to the community. Cladocerans and amphipods contributed 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 17). 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 about 2% to 11% of zooplankton total weight.

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 8-38% of the Sound biomass; an additional 10-20% was contributed by amphipods (Table 18). Copepod biomass (6-56% of the total) contributed a greater percentage to zooplankton than that of cladocerans (5-47%) in most years.

Ichthyoplankton Species Composition

A total of 181,719 larval, postlarval, or young-of-year fishes of 34 finfish species or species groups was collected from the lower Roanoke River, delta, and western Albemarle Sound during the 1984-1991 study (Table 19). Most abundant in larval fish samples were species of Clupeidae (e.g., alewife, blueback herring, American shad, gizzard shad; not including Atlantic menhaden), representing 46.5% of the total enumerated. Striped bass (24.8%) and white perch (7.7%), along with unidentified *Morone* individuals (1.7%), collectively comprised 34% of all fish caught. Minnows (*Notropis* species) represented 11.3% of all fish enumerated. Atlantic menhaden (2.4%), species of Centrarchidae (1.8%), and species of Percidae (1.5%) also were important members of the fish community numerically. Species individually comprising <1% of the total were: common carp, brown bullhead, American eel, sucker species (*Catastomus*), pirate perch, yellow perch, inland silverside, channel catfish, Atlantic needlefish, white catfish, tessellated darter, eastern mudminnow, bay anchovy, longnose gar, redfin pickerel, largemouth bass, striped anchovy, chain pickerel, hogchoker, swamp darter, spot, and Atlantic croaker (Table 19).

Food Habit Analyses

For the larval food and feeding study, the total number of fish enumerated was reduced to include years 1984, 1985, 1986, and 1988; stations were limited to Upriver (Stations 1 and 4), Downriver (Stations 7 and 10), Cashie River (Station 8), Batchelor Bay (Stations 13-15), and western Albemarle Sound (Stations 21 and 22) for a total of 58,517 fish. This total was subsampled for food habit analyses in the manner described previously, reducing the sample size to 7,121 fish (Table 19). The numbers of fish larvae examined by year and species are presented in Tables 20 and 21. Larval fish collected in 1982 and 1983 by the NC Division of Marine Fisheries were added to the data base: 458 fish from Batchelor Bay, and 287 fish from Albemarle Sound (Table 21). The fish collected in 1982 and 1983 were examined for presence of food in stomachs, but were not included in food habit analyses.

With the exception of centrachid species, striped bass had the lowest number of individuals (24.9% of 3,494) with prey present in stomachs. Eighty-two percent of the white perch collected had prey in stomachs (Table 19). Undifferentiated *Morone* larvae had a 67% rate of prey in stomachs of individuals. Species with 90% or more individuals with prey in stomachs were bay anchovy, Atlantic menhaden, brown bullhead, longnose gar, striped mullet, yellow perch, and eastern mudminnow. Only 15% of the centrarchid individuals contained prey in stomachs, the lowest rate of feeding observed for any species.

A number of fish species appeared only rarely in samples, so presentation of feeding results will emphasize selected species based upon abundance and life history strategy: striped bass, white perch, undifferentiated *Morone*, *Notropis*, menhaden, other clupeids, centrarchids, and common carp.

Striped Bass -- Of the 25 finfish species or species groups, striped bass had the second lowest overall feeding rate of 24.9%; the percentage of larvae feeding successfully for specific year and location combinations ranged from a low of 2% to a high of 80%. Within the riverine areas, the percentage of larvae with prey was greatest for all years in the Cashie River. The highest feeding success was observed in 1985 in the Cashie River (80%); feeding success in upriver and downriver areas was close to 50% (Table 22). Note that in 1984, 1986, and 1988 no striped bass larvae in feeding condition were collected from the upstream sites. With the exception of 1984, feeding success in the Sound was similar to that observed in the lower River (Table 23). In 1984, only 17% of the striped bass individuals examined had prey in stomachs, whereas in the other years feeding success was ranged between 35% and 59%. This result was most likely due to the flood conditions present during the spawning season in 1984 (Figure 3).

In general, the primary prey of young striped bass in this system was copepodite copepods, comprising about 22% of the prey biomass in stomachs (Table 24). Other important prey (by biomass) included *Bosmina* (12%), gammarid amphipods (11.6%), and cladocerans other than *Bosmina* (8.5%). Other prey of minor importance included clams, copepod adults, dipteran larvae, and oligochaetes. Prey selection was dependent on fish size. *Bosmina* were consumed primarily by larvae in the 4-, 6-, and 8-mm TL size classes (Figure 12). Striped bass consumption of copepodites was common by the 6-mm size class, and peaked at the 10-mm size class.

White Perch -- Young white perch had a high rate of feeding success, with 696 of 847 individuals (82%) containing prey in stomachs (Table 19). Feeding success ranged from a low of 39% to a high of 100% (9 individuals). In riverine areas, feeding success was similar among locations; values were highest for the Cashie River site in 1986 and 1988 (Table 22). Highest incidence of prey in stomachs was observed in 1985 in the lower Roanoke River (94%) and Cashie River (91%). In Sound locations, feeding success in Batchelor Bay was greatest in 1985 (89%) and 1986 (88%), and poorest in 1988 (39%). White perch young in feeding condition were not present in Albemarle Sound samples from 1984-1986 and 1988 (Table 23).

The primary prey of white perch larvae was *Bosmina*, representing an average of 40% of the stomach biomass of all individuals examined (Table 24). Other major prey included copepodites (12%), rotifers (6%), cladocerans other than *Bosmina* (4%), cladoceran eggs (2%), and copepod adults (1%). Prey of minor importance were dipteran larvae, Ephemiptera, and ostracods. *Bosmina*, copepodites, and rotifers were the primary food of the smallest white perch (Figure 13). *Bosmina* and copepodite copepod importance peaked at the 6-mm size class; too few white perch were present at the larger size classes to determine food habits accurately.

Undifferentiated *Morone* -- This group was a mix of striped bass and white perch larvae that could not be identified to species. Interestingly, this group had a diet different from both striped bass and white perch. The overall feeding success of this group was 67% (Table 19), ranging from a low of 12% in Batchelor Bay in 1984 to a high of 94% in the Cashie River in 1985 (Tables 22 and 23). Primary prey were copepodite copepods (38% of stomach biomass), *Bosmina* (16%), gammarid amphipods (9%), cladocerans other than *Bosmina* (6%), and dipteran larvae (3%). A minor prey was copepod adults. Smallest size classes fed on *Bosmina* and copepodite copepods (Figure 14). The diet shifted dramatically at the 8-mm size class to copepod nauplii, which remained the primary prey through the 20-mm size class. Gammarid amphipods entered the prey menu at the 12-mm size class (Figure 14).

Notropis -- The overall feeding success rate of young minnows was 72% of 1,853 individuals examined for stomach contents (Table 19). Feeding success never dropped below 50% for any year-location combination, and ranged as high as 100% (10 individuals) in Batchelor Bay in 1982 (Tables 22 and 23). Areas of highest feeding success were the Cashie River and Batchelor Bay. Minnows were not collected from the western Albemarle Sound stations (Table 21).

Minnows targeted two major prey: cladocerans other than *Bosmina* and rotifers comprising 24% and 15%, respectively, of the biomass in stomachs (Table 24). Other prey included dipteran larvae (6%), *Bosmina* (5%), copepodite copepods (4%), gammard amphipods (1%), ostracods (1%), and copepod adults (1%). Other prey consumed by minnows included arachnids, clams, Ephemiptera, copepod nauplii, nematodes, and oligochaetes. Rotifers was the primary prey item through the 16-mm size class (Figure 15).

Menhaden -- Only 0.5% of the young menhaden examined had no prey in stomachs (Table 19), a finding not surprising since they are filter feeders on zooplankton. Primary food items by biomass were cladocerans (15%) and *Bosmina* (8%), copepodite copepods (4%) and adults (3%), rotifers (3%), ostracods (1%), turbellarians (1%), and dipteran larvae (1%). Minor food items were arachnids, cladoceran eggs, clams, gammarid amphipods, and nematodes (Table 24). The mouth of the menhaden remains nearly the same size as the body size increases; this phenomenon is reflected in prey as a function of size class (Figure 16). Rotifers and ostracods are consumed at the smallest size classes examined (22-mm); the diet shifts to *Bosmina* and other cladocerans at the 26-mm size class.

Other Clupeids -- This group, encompassing all species of Clupeidae except for the Atlantic menhaden, had an overall feeding success of 43% (Table 19). Feeding success was highly variable among years and locations. In 1984, the area of greatest feeding success was the Cashie River (66%, Table 22). In 1985, the highest feeding success was in Batchelor Bay (61%, Table 23) followed by the Cashie River (54%). Cashie River and Batchelor Bay were the best areas for feeding in 1986, and in 1988 the highest percentage of individuals with prey in stomachs was in Albemarle Sound (50%) and at the upstream (43%) and downstream (40%) sites.

Primary prey of Clupeidae were *Bosmina* (10%) and other cladacerans (14%), rotifers (9%), dipteran larvae (7%), copepodite copepods (2%), and tiny clams (1%). Other prey of minor importance (as stomach biomass) included arachnids, copepod nauplii and adults, Ephemiptera, gammarid amphipods, nematodes, and oligochaetes (Table 24). Rotifers, *Bosmina*, and other cladocerans were consumed through the size class range starting at the 10-mm size class (Figure 17). Copepodites, gammarids, and dipteran larvae and pupae were consumed only at the larger size classes.

Prey Electivity Indices

The Strauss linear electivity index was used to facilitate comparisons of feeding habits among finfish species. The index, ranging in value from -1 to +1, provides an indication of whether the larval fish are consuming prey in proportion to its abundance in the zooplankton (i.e., opportunistic/random feeding) or in a proportion suggestive of selective feeding (positive number) or prey avoidance (negative number). Lechowicz (1982) described and compared seven index algorithms and determined that none of them effectively describe feeding habits under all possible conditions. We selected three indices for possible use in this study: Ivlev's electivity index, Ivlev's forage ratio, and the Strauss linear index (Ivlev 1961, Strauss 1979). Results of the feeding comparisons for all three indices are presented in the appendix. We selected the Strauss linear index for presentation because of the following properties: 1) the value ranges from -1 (avoidance or inaccessibility), to +1 (preference); 2) the expected value for random feeding is zero; and 3) extreme values occur only when they prey item is rare but consumed almost exclusively, or is very abundant but rarely consumed. A fourth index using prey biomass and a stabilizing ratio of ratio comparisons was attempted but not incorporated for this study because of the large number of missing comparisons generated for prey items when no biomass estimate was available.

Electivity index comparisons were generated for seven species of finfish and nine major prey categories in four regions of the Roanoke watershed. The Strauss linear 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.

Bosmina -- Striped bass, white perch, and common carp consumed *Bosmina* in numbers much greater than its proportional density in the zooplankton community (Figure 18). Menhaden and other clupeids, centrarchids, and minnows consumed *Bosmina* at slightly greater proportion in the zooplankton at the most downstream and Sound locations, while consuming the prey at a much lower rate in upstream locations. Note the lack of any pattern in 1984, the year in which the lower Roanoke watershed received high flows from Roanoke Rapids Reservoir upstream.

Other Cladocerans -- Although cladocerans other than *Bosmina* were important prey, they were consumed at numbers much lower than their proportional importance in the zooplankton community (Figure 19). These results may be interpreted to suggest that these prey are inaccessible, either due to prey agility exceeding that of larval fishes, to the physical size of the prey exceeding larval fish mouth size, or to prey avoidance by larval fishes. Whatever the cause, these results indicate that most of the cladoceran zooplankton community is not used as a food source to its maximum potential.

Rotifers -- This major prey item is consumed in quantities much greater than found in zooplankton samples by most larval fish species (Figure 20). Striped bass larvae consumed rotifer prey at a rate approximating rotifer abundance in the zooplankton. Selective feeding on rotifers was most obvious within the lower Roanoke and Cashie rivers. Results for white perch indicate that rotifers are consumed at rates greater than that observed for striped bass (Figure 20).

Copepod Nauplii -- Most fish species consumed copepod nauplii at rates proportionally equal to their density in the zooplankton community (Figure 21), indicating that feeding on this prey item is opportunistic (i.e., random). Nauplii apparently are major and selected prey of young centrarchids.

Copepodid Copepods -- Copepodites are actively selected as prey by several fish species, notably striped bass and white perch (Figure 22). The electivity index values are highest for Batchelor Bay and the Cashie River. Young menhaden, other clupeids, centrarchids, minnows, and carp all consume copepodites in proportions equal to or greater than the prey abundance in the zooplankton community. Evidently this prey item was an important food source for all clupeids and centrarchids in 1984 (Figure 22).

Copepod Adults -- Copepod adults are inaccessible prey to the young fish species examined by this study. Without exception, adult copepods were consumed at proportions less than their abundance in the zooplankton community (Figure 23). This result was similar among locations and among years.

Ostracods -- Ostracods were preyed upon opportunistically or at rates slightly less than the prey abundance in the zooplankton (Figure 24). Both striped bass and white perch exhibited similar patterns of feeding on ostracods among locations and years.

Dipteran Larvae and Pupae -- These prey are not very abundant in the zooplankton community, and rates of consumption among the larval fish species are generally in proportions equal to their densities in the zooplankton community (Figure 25). Striped bass consumed dipterans at proportions higher than that observed for the downstream Roanoke River locations in 1986 and 1988. White perch exibited a similar pattern for the same location in 1988 (Figure 25).

Algae -- Various species of algae were common in stomachs of all finfish species examined, with the exception of striped bass (Figure 26). The frequency of algae occurrence in stomachs was lowest in 1984 and highest in 1986 and 1988. Algae occurrence in white perch individuals was much lower than for the other fish species; an increase of algae in white perch stomachs in 1988 was not evident for striped bass (Figure 26).

DISCUSSION

Primary Production

The composition of 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.

Zooplankton Production

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. The Roanoke results are interesting 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.

Zooplankton as Prey

Zooplankton is the major food source for the larvae and young of all fish species collected from the lower Roanoke River and western Albemarle Sound, but only a limited portion of the zooplankton community is consumed by larval fishes. Of the 90 taxonomic groups identified in the zooplankton, only 24 were found in larval fish stomachs and less than 10 groups were major prey numerically. These major prey items, in terms of both biomass and numbers consumed, were: *Bosmina* and other cladocerans, copepodid copepods, gammarid amphipods, and rotifers. Other important zooplankton prey include copepod adults and nauplii, dipteran larvae and pupae, and ostracods. Several other zooplankton prey were consumed occasionally: arachnids, claderan eggs, tiny pelagically-borne clams of an unidentified species, nematodes, oligochaetes, and turbellaria. Additional rare food items are presented in Table 24.

Ichthyoplankton Feeding Success

We have documented that only about one-fourth of the larval striped bass examined in this study contained prey in stomachs, the second lowest feeding success rate of all species examined. Centrarchids had the lowest percentage of larvae with prey, but the number of specimens examined was not as high as for other major species groups. White perch, the most closely-related species and possessing a similar life history strategy, exhibited a much greater percentage of larvae with prey.

Striped bass appear to be competing directly with other larval fish species for desirable zooplankton prey, primarily *Bosmina*, rotifers, and copepodite copepods. The most abundant members of the zooplankton community -- adult cladocerans and copepods -- are not being utilized to the fullest potential. The lack of feeding success for larval striped bass in the Roanoke watershed is not exhibited by other members of the ichthyoplankton community; the cause may one or several factors: preferred zooplankton abundance too low for young striped bass to feed effectively, or weakened "poor quality" striped bass larvae produced by spawning adults. Larval robustness might be a function of environmental stress on adults during formation of the eggs, a phenomenon known as "habitat squeeze" first proposed by Countant (1985, 1990). An alternative cause for reduced larval health might be poor water quality (e.g., pollutants or inappropriate instream flows).

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 (Rulifson et al. 1992). Since larval transport is directly related to instream flow near the spawning grounds, the speed of 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. (Turner and Chadwick 1972, Chadwick et al. 1977, Stevens 1977). Recruitment success of other anadromous species (e.g., American shad and pacific salmon) are affected by this phenomenon as well (Crecco and Savoy 1984, 1987; Kjelson and Brandes 1987; Stevens et al. 1987; Summers et al. 1990).

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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LITERATURE CITED

APHA. (American Public Health Association). 1975. Standard methods for the examination of water and wastewater. A.P.H.A., New York

Bales, J.D., A.G. Strickland, and R.G. Garrett. 1993. An interim report on flows in the lower Roanoke River, and water quality and hydrodynamics of Albemarle Sound, North Carolina, October 1989-April 1991. Albemarle-Pamlico Estuarine Study, Raleigh, North Carolina, Project No. APES 92-12, 134 p.

Boynton, W.R., T.T. Polgar, and H.H. Zion. 1981. Importance of juvenile striped bass food habits in the Potomac Estuary. Transactions of the American Fisheries Society 110:56-63.

Brandt, S.P., D.M. Mason, and E.V. Patrick. 1992. Spatially-explicit models of fish growth rate. Fisheries (Bethesda) 17:23-35.

Carpenter, E.J. 1971. Annual phytoplankton cycle of the Cape Fear River Estuary, North Carolina. Chesapeake Science 12(2):95-104.

Chadwick, H.K., D.E. Stevens, and L.W. Miller. 1977. Some factors regulating the striped bass population in the Sacramento-San Joaquin Estuary, California, pp. 18-35. In W. Van Winkle (ed.), Proceedings of the Conference on assessing the effects of power-plant-induced mortality in fish populations. Permagon Press, New York.

Coutant, C.C. 1985. Striped bass, temperature, and dissolved oxygen: a speculative hypothesis for environmental risk. Transactions of the American Fisheries Society 114:31-61.

Coutant, C.C. 1990. Temperature-oxygen habitat for freshwater and coastal striped bass in a changing climate. Transactions of the American Fisheries Society 119:240-253.

Crecco, V.A., and T.P. Savoy. 1984. Effect of fluctuations in hydrographic conditions on year class strength of American shad (*Alosa sapidissima*) in the Connecticut River. Canadian Journal of Fisheries and Aquatic Sciences 41:1216-1223.

Crecco, V.A., and T.P. Savoy. 1987. Review of recruitment mechanisms of the American shad: The critical period and match-mismatch hypotheses reexamined. American Fisheries Society Symposium 1:455-468.

Culver, D.A., M.M. Boucherle, D.J. Bean, and J.W. Fletcher. 1985. Biomass of freshwater crustacean zooplankton from length-weight regressions. Canadian Journal of Fisheries and Aquatic Sciences 42:1380-1390.

Dumont, H.J., I. Van de Velde, and S. Dumont. 1975. The dry weight estimate of biomass in a selection of Cladocera, Copepoda, and Rotifera from the plankton, periphyton and benthos of continental waters. Oceologia 19:75-97.

Eldridge, M.B., J. Whipple, and D. Eng. 1981a. Endogenous energy sources as factors affecting mortality and development in striped bass eggs and larvae. In Lasker, R. and K. Sherman, eds. The early life histories of fish: recent studies. Rapp. P-V Reun Cons. Int. Explor. Mer. 178:568-570.

Eldridge, M.B., J.A. Whipple, D. Eng, M.J. Bowers, and N.M. Jarvis. 1981b. Effects of food and feeding factors on laboratory-reared striped bass. Transactions of the American Fisheries Society 110:111-120.

Giese, G.L., H.B. Wilder, and G.G. Parker, Jr. 1985. Hydrology of major estuaries and sounds in North Carolina. U.S. Geological Survey, Water Supply Paper No. 2221.

Gosner, K.L. 1971. Guide to Identification of Marine and Estuarine Invertebrates. Cape Hatteras to the Bay of Fundy. Wiley-Interscience, New York.

Hassler, W.W., H.L. Hill and J.T. Brown. 1981. Status and abundance of striped bass, *Morone saxatilis*, in the Roanoke River and Albemarle Sound, North Carolina, 1956-1980. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Morehead City, Special Scientific Report No. 38.

Henry, L.T. 1993. Commercial and recreational landings of striped bass in Albemarle Sound, 1991-1993, pp. 190-202. In Rulifson, R.A. and C.S. Manooch, III (eds.). 1993. Roanoke River Water Flow Committee Report for 1991-1993. Albemarle-Pamlico Estuarine Study, Raleigh, NC, Project No. APES 93-18.

Henry, L.T. and C.S. Manooch, III. 1993. Relative abundance of species other than striped bass in western Albemarle Sound trawling surveys, 1982-1993. pp. 253-262. In Rulifson, R.A. and C.S. Manooch, III (eds.). 1993. Roanoke River Water Flow Committee Report for 1991-1993. Albemarle-Pamlico Estuarine Study, Raleigh, NC, Project No. APES 93-18.

Henry, L.T. and S.D. Taylor. 1993. Juvenile abundance index of young-of-year striped bass, 1988-1993. In Rulifson, R.A. and C.S. Manooch, III (eds.). 1993. Roanoke River Water Flow Committee Report for 1991-1993. Albemarle-Pamlico Estuarine Study, Raleigh, NC, Project No. APES 93-18.

Herrgesell, P.L., R.G. Schaffter, and C.J. Larsen. 1983. Effects of freshwater outflow on San Francisco Bay biological resources. California Fish and Game, for the Interagency Ecologial Study Program for the Sacramento-San Joaquin Estuary, Technical Report 7.

Ivlev, V.S. 1961. Experimental ecology of the feeding of fishes. Yale University Press, New Haven, Connecticut.

Kareiva,P. and M. Andersen. 1988. Spatial aspects of species interactions: the wedding of models and experiments, pp. 38-54. In A. Hastings (ed.), Community Ecology. Springer-Verlag, New York.

Kernehan, R.J., M.R. Headrick, and R.E. Smith. 1981. Early life history of the striped bass in the Chesapeake Bay and Delaware Canal and vicinity. Transactions of the American Fisheries Society 110:137-150.

Kjelson, M.A. and P.L. Brandes. 1987. The effects of reduced river flows in the Sacramento-San Joaquin Estuary of California on fall-run chinook salmon *(Oncorhynchus tshawytscha)* stocks. U.S. Fish and Wildlife Service, Stockton, California, 54 p.

Laney. R.W., D.L. Stewart, G.R. McCrain, C. Mayes, and V.C. Bruton. 1989. Final report on the North Carolina Department of Transportation Company Swamp Mitigation Bank, Bertie County, North Carolina. U.S. Fish and Wildlife Service, Raleigh Field Office, Raleigh, NC. 37 p. + Appendices.

Lechowicz, M.J. 1982. The sampling characteristics of electivity indices. Oecologia (Berlin) 52:22-30.

Lippson, A.J. and R.L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River Estuary. Power Plant Siting Program, Maryland Department of Natural Resources, Annapolis, 282 p.

Manooch, C. S. III and R. A. Rulifson (eds.). 1989. Roanoke River Water Flow Committee Report: A recommended water flow regime for the Roanoke River, North carolina, to benefit anadromous striped bass and other below-dam resources and users. NOAA Technical Memorandum NMFS-SEFC-216.

Mansueti, R. 1964. Eggs, larvae and young of the white perch, *Roccus americanus*, with comments on its ecology in the estuary. Chesapeake Science 5(1-2):3-45.

Marshall. H.G. 1967. Plankton in James River Estuary, Virginia. I. Phytoplankton in Willoughby Bay and Hampton Roads. Chesapeake Science 8(2):90-101.

Martin, F.D. and R. Malloy. 1981. Histological and morphometric criteria for assessing nutritional state of larval striped bass, *Morone saxatilis*. Maryland Sea Grant Program, UM-SG-RS-81-01, 10 p.

Martin, F.D., D.A. Wright, J.C. Means and E.M. Setzler-Hamilton. 1985. Importance of food supply to nutritional state of larval striped bass in the Potomac River Estuary. Transactions of the American Fisheries Society 114:137-145.

McCafferty, W.P. 1981. Aquatic Entomology. The fishermens' and ecologists' illustrated guide to insects and their relatives. Jones and Bartlett Publishers, Boston, Massachusetts, 448 p.

McCoy, E.G. 1959. Quantitative sampling of striped bass, *Roccus saxatilis* (Walbaum), eggs in the Roanoke River, North Carolina. M.S. Thesis, N.C. State University, Raleigh, 136 p.

McCauley, E. and J. Kalff. 1981. Empirical relationship between phytoplankton and zooplankton biomass in lakes. Canadian Journal of Fisheries and Aquatic Sciences 38:458-463.

Merritt, R.W. and K.W. Cummins. 1984. An introduction to the aquatic insects of North America. Second edition. Kendall/Hunt Publishing Co., Dubuque, Iowa, 722 p.

Mihursky, J.A., W.R. Boynton, E.M. Setzler-Hamilton, K.V. Wood, and T.T. Polgar. 1981. Freshwater influences of striped bass population dynamics. U.S. Fish and Wildlife Service, Biological Services Program FWS/OBS. 81/04. Proceedings of the National Symposium on Freshwater Inflow to Estuaries, Vol. I:31-57.

Mulligan, J., C. Metz, D. Holsinger, R. Swanek, D. Safrit, J. Sauber, N. Bedwell, and S. Gillaspie. 1993. Water quality of the lower Roanoke River Basin, pp. 37-59. In Rulifson, R.A. and C.S. Manooch, III (eds.). 1993. Roanoke River Water Flow Committee Report for 1991-1993. Albemarle-Pamlico Estuarine Study, Raleigh, North Carolina, Project No. APES 93-18.

Nelson, K.L. 1993. Assessment of striped bass spawning stock in Roanoke River, pp. 183-185. In Rulifson, R.A. and C.S. Manooch, III (eds.). 1993. Roanoke River Water Flow Committee Report for 1991-1993. Albemarle-Pamlico Estuarine Study, Raleigh, North Carolina, Project No. APES 93-18.

Ney, J.J. 1990. Trophic economics in fisheries: assessment of demand-supply relationships between predators and prey. Reviews in Aquatic Sciences 2:55-81.

Olney, J.E., G.C. Grant, F.E. Schultz, C.L. Cooper, and J. Hageman. 1983. Pterygiophore-interdigitation patterns in larvae of four *Morone* species. Transactions of the American Fisheries Society 112:525-531.

Pennak, R.W. 1978. freshwater invertebrates of the United States. Ronald Press, New York.

Possingham, H.P. and J. Roughgarden. 1990. Spatial population dynamics of a marine organism with a complex life cycle. Ecology 71:973-985.

Riggs, S.R., C.R. Klingman, and R.A. Wyrick. 1991. Geomorphology and depositional history of the lower Roanoke River and inner Albemarle Sound. NOAA Technical Memorandum NMFS-SEFC-291:7-25.

Riggs, S.R., J.T. Bray, R.M. Wyrick, C.R. Klingman, D.V. Ames, J.C. Hamilton, K.L. Lueck, and J.R. Watson. 1993. Heavy metals in organic-rich muds of the Albemarle Sound estuarine system. Albemarle-Pamlico Estuarine Study, U.S. Environmental Protection Agency, and N.C. Department of Natural Resources and Community Development, Report 93-02, 173 p.

Rozengurt, M. and M. Herz. 1985. Relationship between inflow and commercial/recreational fish catches in the San Francisco Bay. Estuaries 8(2B):29A.

Rulifson, R.A. 1984a. Food and feeding of young striped bass in western Albemarle Sound, North Carolina. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Morehead City, Completion report for Contract C-1366, 47p.

Rulifson, R.A. 1984b. Investigation of possible finfish predators of striped bass (*Morone saxatilis*) in western Albemarle Sound, North Carolina. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Morehead City, Completion Report for Project AFC-18-3, Job 4, 75p.

Rulifson, R.A., and C.S. Manooch, III (eds). 1990a. Roanoke River Water Flow Committee report for 1988 and 1989. NOAA Technical Memorandum NMFS-SEFC-256.

Rulifson, R.A., and C.S. Manooch, III. 1990b. Recruitment of juvenile striped bass in the Roanoke River, North Carolina, as related to reservoir discharge. North American Journal of Fisheries Management 10:397-407.

Rulifson, R.A., and C.S. Manooch, III (eds). 1991. Roanoke River Water Flow Committee report for 1990. NOAA Technical Memorandum NMFS-SEFC-291.

Rulifson, R.A. and C.S. Manooch, III (eds). 1993. Roanoke River Water Flow Committee Report for 1991-1993. Published by the Albemarle-Pamlico Estuarine Study, Raleigh, North Carolina. Project No. APES 93-18, 384 p.

Rulifson, R.A. and D.W. Stanley. 1985. Food and feeding of young striped bass in Roanoke River and western Albemarle Sound, North Carolina: 1984. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Morehead City, Annual Progress Report for Project AFS-24, Segment 1, 252 p.

Rulifson, R.A., D.W. Stanley, and J.E. Cooper. 1986a. Food and feeding of young striped bass in Roanoke River and western Albemarle Sound, North Carolina, 1984-1985. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Morehead City, Completion Report for Project AFS-24.

Rulifson, R.A., J.E. Cooper, and G. Colombo. 1986b. Development of fed and starved striped bass (*Morone saxatilis*) larvae from the Roanoke River, North Carolina. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Morehead City, Completion Report for ECU Grant/Contract No. 5-21431.

Rulifson, R.A., J.E. Cooper, and D.W. Stanley. 1988. Larval striped bass and the food chain: cause for concern? American Water Resources Association, Technical Publication Series TPS-88-1:213-224.

Rulifson, R.A., R.E. Herrmann, J.T. Bray, and W.M. White. 1990. Water quality as a function of discharge from the Roanoke Rapids Reservoir during hydropower generation. Albemarle-Pamlico Estuarine Study, Raleigh, North Carolina, Project No. APES 90-12.

Rulifson, R.A., M.T. Huish, and R.W. Thoesen. 1982. Anadromous fish in the southeastern United States and recommendations for the development of a management plan. U.S. Fish and Wildlife Service, Fishery Resources, Region 4, Atlanta, Georgia, 525 p.

Rulifson, R.A., J.E. Cooper, D.W. Stanley, M.E. Shepherd, S.F. Wood, and D.A. Daniel. 1992a. Food and feeding of young striped bass in Roanoke River and western Albemarle Sound, North Carolina, 1984-1991. N.C. Wildlife Resources Commission, Raleigh, Completion Report for Project F-27.

Rulifson, R.A., J.E. Cooper, D.W. Stanley, M.E. Shepherd, S.F. Wood, and D.A. Daniel. 1992b. Food and feeding of young striped bass in Roanoke River and western Albemarle Sound, North Carolina, 1990-1991. N.C. Wildlife Resources Commission, Raleigh, and North Carolina Striped Bass Study Management Board, Completion Report for Projects 90-2 and 91-2, 62 p.

Rulifson, R.A., C.S. Manooch, III, and J.J. Isely. 1993. Striped bass egg abundance and viability in the Roanoke River, North Carolina, and young-of-year survivorship, for 1992. North Carolina Division of Marine Fisheries, Morehead City, Completion Report for Project F-50, 169 p.

Setzler-Hamilton, E.M., D.A. Wright, F.D. Martin, C.V. Millsaps, and S.I. Whitlow. 1987. Analysis of nutritional condition and its use in predicting striped bass recruitment: field studies. American Fisheries Society Symposium 2:115-128.

Stanley, D.W. and D. A. Daniel. 1985. Phytoplankton in the Pamlico Estuary: 1984. Institute for Coastal and Marine Resources Technical Report No. 85-01. East Carolina University, Greenville, North Carolina.

Stevens, D.E. 1977. Striped bass (*Morone saxatilis*) year class strength in relation to river flow in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 106:34-42.

Stevens, D.E., D.W. Kohlhorst, L.W. Miler, and D.W. Kelley. 1985. The decline of striped bass in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 114:12-30.

Stevens, D.E., H.K. Chadwick, and R.E. Painter. 1987. American shad and striped bass in California's Sacramento-San Joaquin Estuary, California. American Fisheries Society Symposium 1:66-78.

Strauss, R.E. 1979. Reliability estimates for Ivlev's electivity index, the forage ratio, and a proposed linear index of food selection. Transactions of the American Fisheries Society 108:344-352.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis. Journal of the Fisheries Research of Canada 167, 311 p.

Summers, J.K., W.A. Richkus, C.F. Stroup, and L.J. Rugolo. 1990. The influence of natural and anthropogenic environmental change on white perch stock status in the Choptank River, Maryland. Fisheries Research 9:255-268.

Turner, J.L. and H.K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, *Morone saxatilis*, in relation to river flow in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 101:442-452.

USDOI and USDOC (U.S. Department of the Interior and U.S. Department of Commerce). 1985. Emergency striped bass research study. 1984 Annual report, Washington, D.C.

U.S. Army Corps of Engineers. 1968. Review report on Roanoke River, Virginia, and North Carolina, at and below J.H. Kerr Dam and Reservoir, Volume II, Appendices A-D. South Atlantic Division, Wilmington District, Wilmington, North Carolina.

U.S. Army Corps of Engineers. 1984. Feasibility report and final environmental impact statement, water supply study, Hampton Roads, Virginia, Chowan River and tributaries, Virginia and North Carolina. North Atlantic Division, Norfolk District, Norfolk, Virginia.

Valiella, I. 1984. Marine Ecological Processes. Springer-Verlag, New York, 546 p.

Wetzel, R.G. and G.E. Likens. 1979. Limnological analyses. W.B. Saunders, Philadelphia, 357 p.

Table 1. Scientific and common names for fish of known or probable occurrence in the Roanoke River and Coniot Creek in the vicinity of Company Swamp, Bertie County, North Carolina (after Laney et al. 1989).

Family	Common Name	Scientific Name
Acipenseridae	Atlantic sturgeon	*Acipenser oxyrhynchus*
	Shortnose sturgeon	*Acipenser brevirostrum*
Lepisosteidae	Longnose gar	*Lepisosteus osseus*
Amiidae	Bowfin	*Amia calva*
Anguillidae	American eel	*Anguilla rostrata*
Clupeidae	Alewife	*Alosa pseudoharengus*
	American shad	*Alosa sapidissima*
	Atlantic menhaden	*Brevoortia tyrannus*
	Blueback herring	*Alosa aestivalis*
	Gizzard shad	*Dorosoma cepedianum*
	Hickory shad	*Alosa mediocris*
Umbridae	Eastern mudminnow	*Umbra pygmaea*
Esocidae	Chain pickerel	*Exos niger*
	Redfin pickerel	*Esox americanus*
Cyprinidae	Bluehead chub	*Nocomis leptocephalus*
	Carp	*Cyprinus carpio*
	Creek chub	*Semotilus atromaculatus*
	Golden shiner	*Notemigonus crysoleucas*
	Ironcolor shiner	*Notropis chalybeaus*
	Satinfin shiner	*Cyprinella analostana*
	Silvery minnow	*Hybognathus regius*
	Spottail shiner	*Notropis hudsonius*
	Swallowtail shiner	*Notropis procne*
	White shiner	*Notropis albeolus*
Catostomidae	Creek chubsucker	*Erimyzon oblongus*
	Shorthead redhorse	*Moxostoma macrolepidotum*
	Silver redhorse	*Moxostoma anisurum*
	Suckermouth redhorse	*Moxostoma papallosum*
Ictaluridae	Brown bullhead	*Ameiurus nebulosus*
	Channel catfish	*Ictalurus punctatus*
	Margined madtom	*Noturus insignis*
	Tadpole madtom	*Noturus gyrinus*
	White catfish	*Ameiurus catus*
	Yellow bullhead	*Ameiurus natalis*

Table 1 (continued).

Family	Common Name	Scientific Name
Amblyopsidae	Swampfish	*Chologaster cornuta*
Aphredoderidae	Pirate perch	*Aphredoderus sayanus*
Cyprinodontidae	Lined topminnow	*Fundulus lineolatus*
Poeciliidae	Eastern mosquitofish	*Gambusia holbrooki*
Percichthyidae	Striped bass	*Morone saxatilis*
	White perch	*Morone americana*
Centrarchidae	Banded sunfish	*Enneacanthus obesus*
	Banded pygmy sunfish	*Elassoma zonatum*
	Black crappie	*Pomoxis nigromaculatus*
	Blackbanded sunfish	*Enneacanthus chaetodon*
	Bluegill	*Lepomis macrochirus*
	Bluespotted sunfish	*Enneacanthus gloriosus*
	Flier	*Centrarchus macropterus*
	Green sunfish	*Lepomis cyanellus*
	Largemouth bass	*Micropterus salmoides*
	Mud sunfish	*Acantharchus pomotis*
	Pumpkinseed	*Lepomis gibbosus*
	Redbreast sunfish	*Lepomis auritus*
	Warmouth	*Lepomis gulosus*
	White crappie	*Pomoxis annularis*
Percidae	Glassy darter	*Etheostoma vitreum*
	Johnny darter	*Etheostoma nigrum*
	Sawcheek darter	*Etheostoma serriferum*
	Swamp darter	*Etheostoma fusiforme*
	Tessellated darter	*Etheostoma olmstedi*
	Yellow perch	*Perca flavescens*

Table 2. NPDES dischargers to the lower Roanoke River Basin (Rulifson et al. 1990).

Discharger	Permitted Waste Volume (mgd)	Permitted BOD concent. 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	--
Williamson 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	--

Table 3. Descriptions of the fixed sampling locations used in the striped bass food and feeding study, 1982-1988. 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
2	35:48:15N, 76:53:45W (RM 19)	Jamesville - similar to Station 1	1984-1988
3	35:48:15N, 76:53:45W (RM 16)	Downstream of Jamesville- similar to Station 1	1984-88
4	35:50:00N, 76:51:45W (RM 14)	Power lines - similar to Station 1; several "snags"	1984-1988
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.	1984-1988
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.	1984-1988
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.	1984-1988
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.	1984-1988
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.	1984-1988

Table 3 (continued).

Station number	Approximate latitude/ longitude	Physical description	Years sampled
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.	1984-1988
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.	1984-1988
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.	1984-1988
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.	1982-1988
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.	1982-1986
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.	1982-1988
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, 1987-1988
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.	1982-1984, 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.	1982-1984 1987-1988

Table 3 (continued).

Station number	Approximate latitude/ longitude	Physical description	Years sampled
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.	1982-1983 1986-1988
21	35:57:05N, 76:39:20W	Southwest Albemarle 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.	1986-1988
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.	1982-1983 1986-1988
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.	1986-1988
24	36:01:25N, 76:35:35W	Northwest Albemarle Sound; mean depth 4.3 m, maximum 5.5 m.	1986-1988
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.	1986-1988
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
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.	1986-1988
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

Table 3 (continued).

Station number	Approximate latitude/ longitude	Physical description	Years sampled
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.	1987-1988
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.	1987-1988

Table 4. 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 4 (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 4 (continued).

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

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 (1982-83, 1985-87, 1989, 1990); n=366 days (1984, 1988).

	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.	Mean	S.E.	Days	%	Days	%	Days	%	Days	%	Days	%
1982	7,613	270	8,779	569	19	20.9	7	7.7	33	36.3	32	35.1	0	0.0
1983	9,534	395	16,278	813	9	9.9	4	4.4	11	12.1	29	31.9	38	41.8
1984	10,091	359	13,836	716	12	13.2	2	2.2	16	17.6	26	28.6	35	38.5
1985	7,392	321	3,573	197	58	63.7	12	13.2	21	23.1	0	0	0	0
1986	4,157	146	4,252	206	42	46.2	29	31.9	18	19.8	2	2.2	0	0
1987	12,213	494	19,596	1,207	6	6.6	6	6.6	15	16.5	20	22.0	44	48.4
1988	4,668	176	5,412	282	27	29.7	22	24.2	38	41.8	4	4.4	0	0
1989	10,747	332	13,699	596	1	1.1	9	9.9	22	24.2	29	31.9	30	33.0
1990	10,495	353	13,386	574	3	3.3	2	2.2	32	35.2	42	46.2	12	13.2

[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 1963-1991 (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.

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.

Water quality parameter	1988 Upstream	 Delta	1990 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

Table 8. Most frequently occurring phytoplankton taxa, and their relative occurrence in samples (%), in the lower Roanoke River and western Albemarle Sound, North Carolina, from spring 1984 through spring 1988. Class BAC = Bacillariophyceae; CHL = Chlorophyceae; CHR = Chrysophyceae; EUG = Euglenophyceae; UNK = Unknown.

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

Table 9. Relative contribution (% using density) of each taxonomic group to the spring zooplankton community of the lower Roanoke River (Stations 1-12), North Carolina, 1984-1988. 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 9. 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 10. Relative contribution (% using density) of each taxonomic group to the spring zooplankton community of Batchelor Bay (Stations 13-16), North Carolina, 1984-1988. 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 10. 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 11. Relative contribution (% using density) of each taxonomic group to the spring zooplankton community of Western Albemarle Sound (Stations 17-32), North Carolina, 1984-1988. 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 11. 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 12. 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, 1984-1988.

		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 12. Zooplankton mean lengths and widths (continued).

		Length (mm)				Width (mm)			
Taxonomic group	n	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 13. 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 14. 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, 1984-1988. 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 14. Zooplankton wet weight biomass (continued).

	Wet weight biomass per animal (g)					Dry biomass	
Taxonomic group	n	Mean	S.D.	Min	Max	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 15. 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 16. Relative contribution (% using biomass) of each taxonomic group to the spring zooplankton community of the lower Roanoke River (Stations 1-12), North Carolina, 1984-1988. 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 16. 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 17. Relative contribution (% using biomass) of each taxonomic group to the spring zooplankton community of Batchelor Bay (Stations 13-16), North Carolina, 1984-1988. 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 17. 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

Table 18. Percent contribution (% using biomass) of each taxonomic group to the spring zooplankton community of Western Albemarle Sound (Stations 17-32), North Carolina, 1984-1988. 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 18. 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 19. Fish species collected in the lower Roanoke River - western Albemarle Sound study area as larvae or young-of-year, 1984-1991, and the number counted, examined, and containing prey in stomachs, for the data subset used in this study (Years 1984-86, 1988; Stations 1, 4, 7, 10, 13-15, and 21-22).

Species code	Common name	Scientific name	Total number counted 1984-91	1984-86 and 1988 data subsets			
				number counted	number examined	number foodfood	% with
ALAE	blueback herring	*Alosa aestivalis*	2	0	0	-	-
ALPS	alewife	*Alosa pseudoharengus*	1	0	0	-	-
ALME	hickory shad	*Alosa mediocris*			recoded as CLUP		
ALSA	American shad	*Alosa sapidissima*			recoded as CLUP		
ANHE	striped anchovy	*Anchoa hepsetus*	3	0	0	-	-
ANMI	bay anchovy	*Anchoa mitchelli*	7	1	2	2	100.0
ANRO	American eel	*Anguilla rostrata*	165	77	73	52	71.2
APSA	pirate perch	*Aphrododerus sayanus*	148	14	10	5	50.0
BRTY	Atlantic menhaden	*Brevoortia tyrannus*	4,354	2,096	1,078	1,073	99.5
CATA	sucker species	*Catastomus* species	180	54	47	37	78.7
CENT	centrarchid species	Centrarchidae (unid.)	3,247	655	355	56	15.8
CLUP	clupeid species	Clupeidae (unid.)	84,530	28,872	5,035	2,184	43.4
CYCA	common carp	*Cyprinus carpio*	1,603	172	65	28	43.1
ESAM	redfin pickerel	*Esox americanus*	4	0	1	0	0.0
ESNI	chain pickerel	*Esox niger*	2	0	0	-	-
ETFU	swamp darter	*Etheostoma fusiforme*	1	0	0	-	-
ETOL	tessellated darter	*Etheostoma olmstedi*	18	0	0	-	-
ICCA	white catfish	*Ameiurus catus*	18	7	8	7	87.5
ICNE	brown bullhead	*Ameiurus nebulosus*	199	64	62	58	93.5
ICPU	channel catfish	*Ictalurus punctatus*	23	6	4	4	100.0
LEOS	longnose gar	*Lepisosteus osseus*	7	0	0	-	-
LEXA	spot	*Leiostomus xanthurus*	1	0	0	-	-
MEBE	inland silverside	*Menidia beryllina*	72	9	12	5	41.7
MISA	largemouth bass	*Micropterus salmoides*	3	0	0	-	-
MIUN	Atlantic croaker	*Micropogonias undulatus*	1	0	0	-	-
MOAM	white perch	*Morone americana*	14,074	5,620	847	696	82.2
MOSA	striped bass	*Morone saxatilis*	45,092	13,855	3,494	871	24.9

Table 19. Continued.

Species code	Common name	Scientific name	Total number counted 1984-91	1984-86 and 1988 data subsets			
				number counted	number examined	number food	% with food
MOSP	Morone, undifferentiated	*Morone* species (unid.)	3,141	1,402	756	507	67.1
MUCE	striped mullet	*Mugil cephalus*	1	1	1	1	100.0
NOSP	Notropis species	*Notropis* species	20,469	4,621	1,853	1,344	72.5
PEFL	yellow perch	*Perca flavescens*	132	87	43	41	95.3
PERC	perch species	Percidae (unid.)	2,645	651	165	142	86.1
STMA	Atlantic needlefish	*Strongylura marina*	19	11	7	4	57.1
TRMA	hogchoker	*Trinectes maculatus*	2	2	2	2	100.0
UMPY	eastern mudminnow	*Umbra pygmaea*	8	3	3	2	66.7
UNID	unidentified	unidentifed species	1,547	237	0	-	-
Total examined			181,719	58,517	13,923	7,121	51.1

Table 20. Number of individuals examined for food habit analysis for upstream Roanoke River stations (1,4), downstream Roanoke stations (7,10), and the Cashie River (8).

		Upriver				Downriver				Cashie River				Total
	Species	84	85	86	88	84	85	86	88	84	85	86	88	examined
MOSA	striped bass	0	101	0	3	0	410	1288	283	0	114	241	224	2664
MOAM	white perch	0	23	7	19	0	249	70	30	0	45	18	13	474
MOSP	unid. Morone	0	0	0	0	0	242	9	0	0	176	5	0	432
CLUP	clupeids	131	79	90	180	204	658	326	224	178	713	385	51	3219
NOSP	minnow sp.	312	182	266	166	217	8	97	127	238	14	7	70	1704
BRTY	Atl. menhaden	0	7	7	7	0	11	85	55	4	81	231	286	774
CENT	sunfish sp.	8	6	0	3	73	20	23	21	37	23	16	15	245
PERC	darter sp.	13	1	4	5	17	4	7	7	47	2	5	3	115
CATA	sucker sp.	5	0	1	30	5	0	1	4	0	0	0	0	46
CYCA	common carp	8	1	4	5	11	5	1	1	0	8	0	0	44
ANRO	American eel	0	0	0	0	0	0	0	1	3	3	4	14	25
ICNE	brown bullhead	0	0	0	0	10	1	0	1	5	2	1	0	20
PEFL	yellow perch	1	0	0	3	3	2	0	3	0	4	3	0	19
APSA	pirate perch	2	0	0	3	1	0	0	1	1	0	0	2	10
STMA	Atl. needlefish	0	0	0	0	2	0	0	0	1	0	0	0	3
UMPY	eastern mudminnow	1	0	0	0	2	0	0	0	0	0	0	0	3
ICCA	white catfish	0	0	0	0	0	0	0	0	2	0	0	0	2
MUCE	striped mullet	0	0	0	0	0	0	0	0	0	1	0	0	1
ANMI	bay anchovy	0	0	0	0	0	0	0	0	0	0	0	1	1
ESAM	redfin pickerel	0	0	0	0	1	0	0	0	0	0	0	0	1
ICPU	channel catfish	0	0	0	0	0	0	1	0	0	0	0	0	1
MISA	largemouth bass	0	0	0	0	0	0	0	0	0	0	0	0	0
FUHE	mummichog	0	0	0	0	0	0	0	0	0	0	0	0	0
MEBE	inl. silverside	0	0	0	0	0	0	0	0	0	0	0	0	0
TRMA	hogchoker	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 21. Number of individuals examined for food habit analysis for Batchelor Bay (13-15), and western Albemarle Sound (21,22).

		Batchelor Bay						Albemarle Sound						Total
	Species	82	83	84	85	86	88	82	83	84	85	86	88	examined
MOSA	striped bass	0	0	6	147	431	210	0	0	6	0	1	35	836
MOAM	white perch	0	3	0	315	98	18	9	57	0	0	0	0	500
MOSP	unid. Morone	0	0	17	225	11	4	0	0	0	0	0	35	292
CLUP	clupeids	123	189	310	1254	281	71	65	129	0	0	1	10	2433
NOSP	minnow sp.	10	87	165	18	25	16	0	0	0	0	0	0	321
BRTY	Atl. menhaden	12	0	3	97	165	26	9	0	0	0	15	4	331
CENT	sunfish sp.	0	14	69	9	10	23	0	11	0	0	0	1	137
PERC	darter sp.	0	1	21	5	44	2	0	1	0	0	0	0	74
CATA	sucker sp.	0	0	1	0	0	0	0	0	0	0	0	0	1
CYCA	common carp	1	2	4	19	4	0	0	0	0	0	0	0	30
ANRO	American eel	2	10	15	5	10	19	4	0	0	0	0	0	65
ICNE	brown bullhead	0	0	31	2	5	4	0	0	0	0	0	0	42
PEFL	yellow perch	0	0	0	20	15	1	0	0	0	0	0	0	36
APSA	pirate perch	0	0	2	0	0	0	0	0	0	0	0	0	2
STMA	Atl. needlefish	0	0	1	2	1	0	0	0	0	0	0	0	4
UMPY	eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0	0	0
ICCA	white catfish	0	0	5	1	0	0	0	0	0	0	0	0	6
MUCE	striped mullet	0	1	0	0	0	0	0	0	0	0	0	0	1
ANMI	bay anchovy	0	0	0	0	1	0	1	0	0	0	0	0	2
ESAM	redfin pickerel	0	0	0	0	0	0	0	0	0	0	0	0	0
ICPU	channel catfish	0	0	0	0	0	3	0	1	0	0	0	0	4
MISA	largemouth bass	1	0	0	0	0	0	0	0	0	0	0	0	1
FUHE	mummichog	0	1	0	0	0	0	0	0	0	0	0	0	1
MEBE	inl. silverside	0	1	0	0	8	0	0	0	0	2	1	1	13
TRMA	hogchoker	0	0	2	0	0	0	0	0	0	0	0	0	2

Table 22. Percentage of individuals with prey in stomachs from upriver stations (1,4), downriver stations (7,10), and Cashie River (8). Parentheses () indicate a value for only one specimen.

		Upriver				Downriver				Cashie River			
	Species	1984	1985	1986	1988	1984	1985	1986	1988	1984	1985	1986	1988
MOSA	striped bass		48				45	2	2		80	46	20
MOAM	white perch		43	71	53		94	53	63		91	83	77
MOSP	unid. Morone						38	67			94	80	
CLUP	clupeids	31	33	20	43	14	18	25	40	66	54	48	28
NOSP	minnow sp.	82	85	56	52	65	50	62	50	91	64	86	91
BRTY	Atl. menhaden		100	100	100		100	100	100	100	100	100	100
CENT	sunfish sp.	38	17		33	15	20	17	10	8	9	25	20
PERC	darter sp.	77	(100)	75	80	71	100	71	29	96	100	100	100
CATA	sucker sp.	20		(100)	93	20		(100)	100				
CYCA	common carp	63	(100)	100	100	36	20	(0)	(100)		38		
ANRO	American eel								0)	100	67	75	71
ICNE	brown bullhead					100	(100)		(100)	100	100	(0)	
PEFL	yellow perch	(100)			33	100	100		100		100	100	
APSA	pirate perch	0			33	(100)			(100)	(100)			100
STMA	Atl. needlefish					0				(100)			
UMPY	eastern mudminnow	(100)					50						
ICCA	white catfish									100			
MUCE	striped mullet										100		
ANMI	bay anchovy												(100)
ESAM	redfin pickerel					0							
ICPU	channel catfish							100					
MISA	largemouth bass												
FUHE	mummichog												
MEBE	inl. silverside												
TRMA	hogchoker												

Table 23. Percentage of individuals containing prey in stomachs for Batchelor Bay (Stations 13-15) and western Albemarle Sound (Stations 21 and 22). Parentheses () indicate a value for only one specimen.

		Batchelor Bay						Albemarle Sound					
	Species	1982	1983	1984	1985	1986	1988	1982	1983	1984	1985	1986	1988
MOSA	striped bass			17	59	45	35			17		(100)	46
MOAM	white perch		67		89	88	39	100	44				
MOSP	unid. Morone			12	84	82	75						
CLUP	clupeids	29	90	39	61	41	15	42	50		(100)		50
NOSP	minnow sp.	100	99	98	78	96	81						
BRTY	Atl. menhaden	83		100	100	98	100	100			(100)	100	100
CENT	sunfish sp.		43	13	33	20	22		55				(0)
PERC	darter sp.		(100)	90	100	98	50		(100)				
CATA	sucker sp.			(100)									
CYCA	common carp	(100)	100	50	11	0	38						
ANRO	American eel	100	60	87	40	60	74	25					
ICNE	brown bullhead			100	0	80	100						
PEFL	yellow perch				100	100	(100)						
APSA	pirate perch			50									
STMA	Atl. needlefish			(100)	50	(100)							
UMPY	eastern mudminnow												
ICCA	white catfish			80		(100)							
MUCE	striped mullet		(100)										
ANMI	bay anchovy					(100)		(100)					
ESAM	redfin pickerel												
ICPU	channel catfish						100		(100)				
MISA	largemouth bass	(100)											
FUHE	mummichog		(100)										
MEBE	inl. silverside		(100)			38					0	(100)	(100)
TRMA	hogchoker			100									

Table 24. Average relative proportion (%) of prey biomass present in stomachs of larval fish species collected from the Roanoke River and western Albemarle Sound, 1984-1986 and 1988. Number of specimens examined in parentheses.

Prey	White perch (696)	Striped bass (871)	Morone species (507)	Striped mullet (1)	Notropis species (1,361)	Yellow perch (41)	Perid speces (12)		Atlantic needlefish (4)		Hogchoker (2)		UMPY (2)
Arachnid	0.0	0.0	0.0	0.0	0.9	0	.4	4	0.0	2	0	2	0
Bee, wasp	0.0	0.0	0.0	0.0	0.0	0	.4	4	0.0	2	0	2	0
Bosmina	40.1	12.0	15.9	0.0	4.8	24.2	0	4	0.2	2	0	2	0
Bryozoan	0.0	0.0	0.0	0.0	0.0	0	.4	4	0.0	2	0	2	0
Clad-egg	2.0	0.0	0.0	0.0	0.0	0	0	4	0.0	2	0	2	0
Clad-other	4.4	8.5	6.0	0.0	24.0	43.1	0	4	0.0	2	.	2	0
Clam	0.0	0.5	0.0	0.0	0.9	0	.9	4	0.0	2	99.6	2	0
Cope-adult	1.4	0.1	0.1	0.0	1.0	0.2	0	4	0.0	2	.	2	0
Cope-egg	0.0	0.0	0.0	0.0	0.0	0.3	0	4	0.0	2	0	2	0
Copepodite	12.3	21.7	37.9	0.0	4.3	15.8	0	4	0.0	2	0	2	0
Detritus	0.0	0.0	0.0	0.0	0.0	0	.1	4	0.0	2	0	2	19.8
Dipt-adult	0.0	0.0	0.0	0.0	0.0	0	0	4	0.0	2	0	2	0
Dipt-larvae	0.3	0.4	3.1	0.0	6.5	6.3	0	4	0.0	2	.	2	0
Ephemiptera	0.1	0.0	0.0	0.0	0.1	0	.4	4	0	2	0	2	0
Fish	0.0	0.0	0.0	0.0	0.0	0	.6	4	0	2	0	2	0
Gammarid	0.0	11.6	9.0	0.0	1.2	4	.6	4	0	2	0	2	0
Glochidia	0.0	0.0	0.0	0.0	0.0	0	0	4	0	2	0	2	0
Cope-nauplii	0.0	0.0	0.0	0.0	0.1	0	.7	4	0	2	0	2	0
Nematode	0.0	0.0	0.0	0.0	0.3	0	0	4	0	2	0	2	0
Oligochaeta	0.0	0.3	0.0	0.0	0.4	0	0	4	0	2	0	2	0
Ostracod	0.1	0.0	0.0	0.0	1.1	0	0	4	0	2	.	2	0
Rotifer	5.5	0.0	0.0	0.0	14.6	0	0	4	0	2	0	2	0
Spongillafly	0.0	0.0	0.0	0.0	0.0	0	0	4	0	2	0	2	0
Turbellaria	0.0	0.0	0.0	0.0	0.0	0	0	4	0	2	.	2	0
Unidentified	0.0	0.0	0.0	0.0	0.0	0	0	4	0	2	.	2	0

Table 24 (continued).

	Striped anchovy (2)	American eel (52)	Pirate perch (6)	Atlantic menhaden (1,073)	Sucker species (37)	Sunfish family (56)	Other clupeids (2,184)	Common carp (28)	Redfin pickerel	White catfish (4)	Brown bullhead (2)	Channel catfish (2)	
Arachnid	0.0	0.0	0.0	0.4	0.0	0.0	0.3	0.0	0	7.0	58	4	0
Bee, wasp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0	0	0
Bosmina	0.0	0.0	5.0	7.5	7.4	3.3	10.1	16.9	0	0.0	.	0	0
Bryozoan	.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.5	27.4	0	0	.
Clad-egg	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	2.1	0.0	0	0	0
Clad-other	48.2	10.6	16.7	15.1	46.2	8.1	14.0	11.8	12.5	29.6	0.4	13.6	61.4
Clam	0.0	0.0	0.0	0.1	2.8	0.0	1.0	0.0	0	0.0	0	0	0
Cope-adult	22.6	0.8	0.0	2.7	0.1	0.0	0.6	0.0	0.4	0.0	0	0	22
Cope-egg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0	0	0
Copepodite	0.0	6.2	40.2	4.2	7.0	1.3	2.3	3.6	0.6	0.0	0	0	0
Detritus	.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0	0	.
Dipt-adult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0	0	16.7
Dipt-larvae	1.4	15.7	0.0	1.0	1.6	0.3	7.4	0.0	0	0.0	0	0	0
Ephemiptera	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0	7.0	58	4	0
Fish	.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	.	0	.
Gammarid	0.0	5.5	0.0	0.1	0.0	0.0	0.3	0.0	0	0	0	0	0
Glochidia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0
Cope-nauplii	0.0	0.0	0.0	0.0	0.0	0.4	0.3	0.0	3.1	0	0	19.8	0
Nematode	0.0	0.0	0.0	0.4	0.0	0.0	0.3	0.0	0	0	0	0	0
Oligochaete	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0	0	.	0	0
Ostracod	0.3	1.3	0.0	1.5	0.0	0.0	0.8	0.0	0	0	0	0	0
Rotifer	27.4	0.0	0.0	3.5	8.0	3.6	8.8	0.0	0	0	0	0	0
Spongillafly	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	.	0	0
Turbellaria	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0	0	0	0	0
Unidentified	.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	7	58	4	.

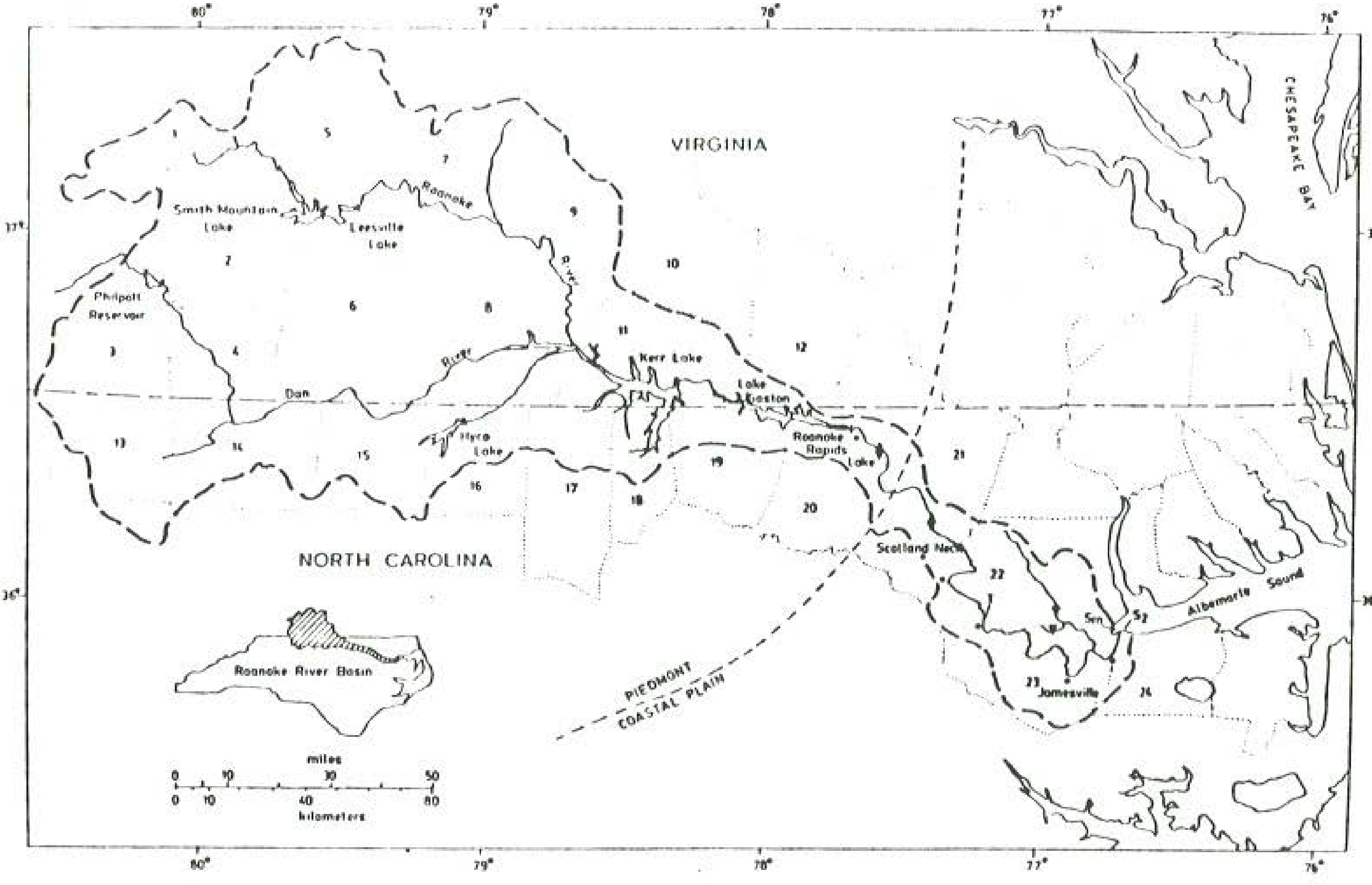


Figure 1. Drainage area of the Roanoke River Basin (from Manooch and Rulifson 1989).

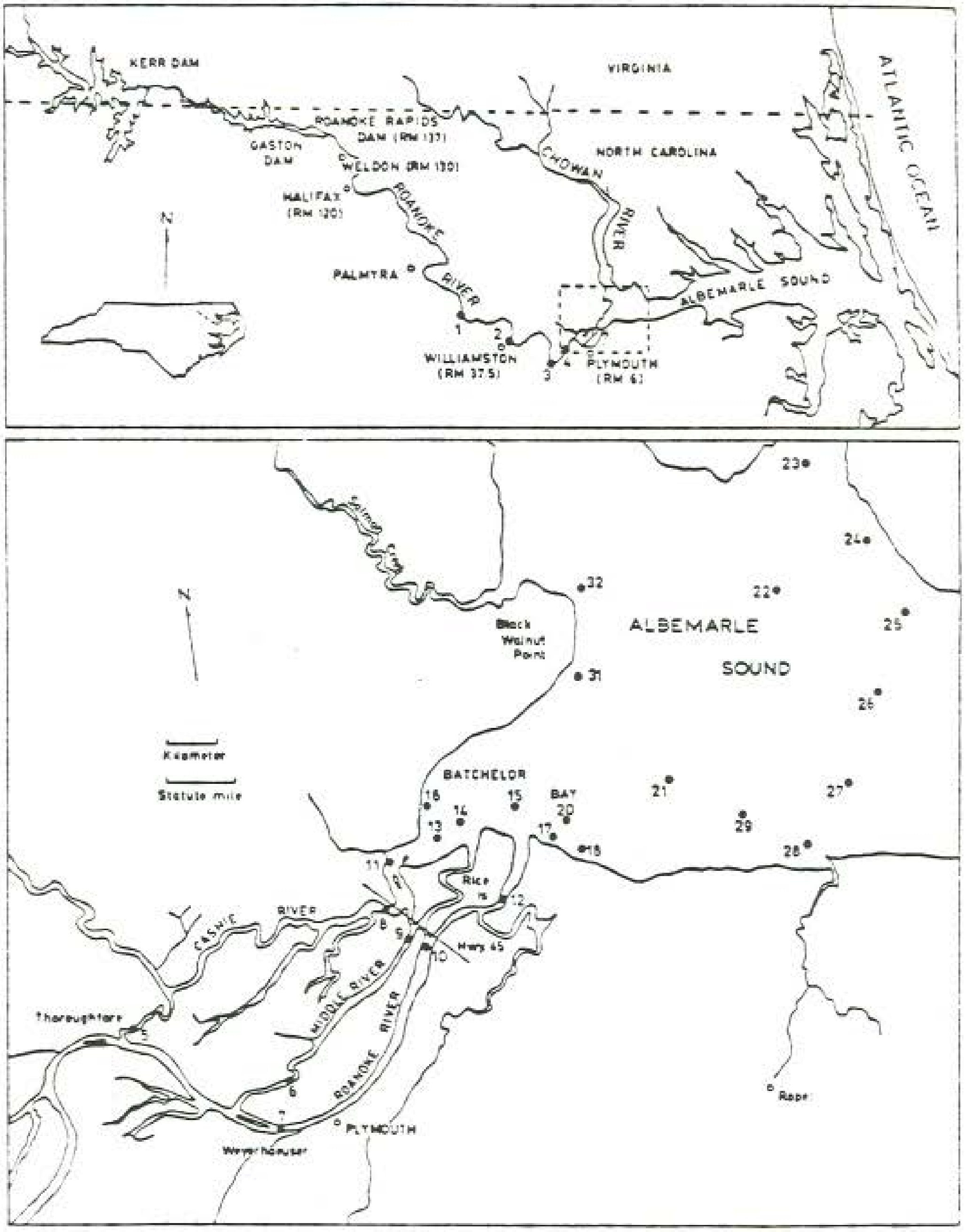


Figure 2. Map depicting the locations of sampling sites used during the 1982-1988 period. Refer to Table 3 for years in which each section was sampled.

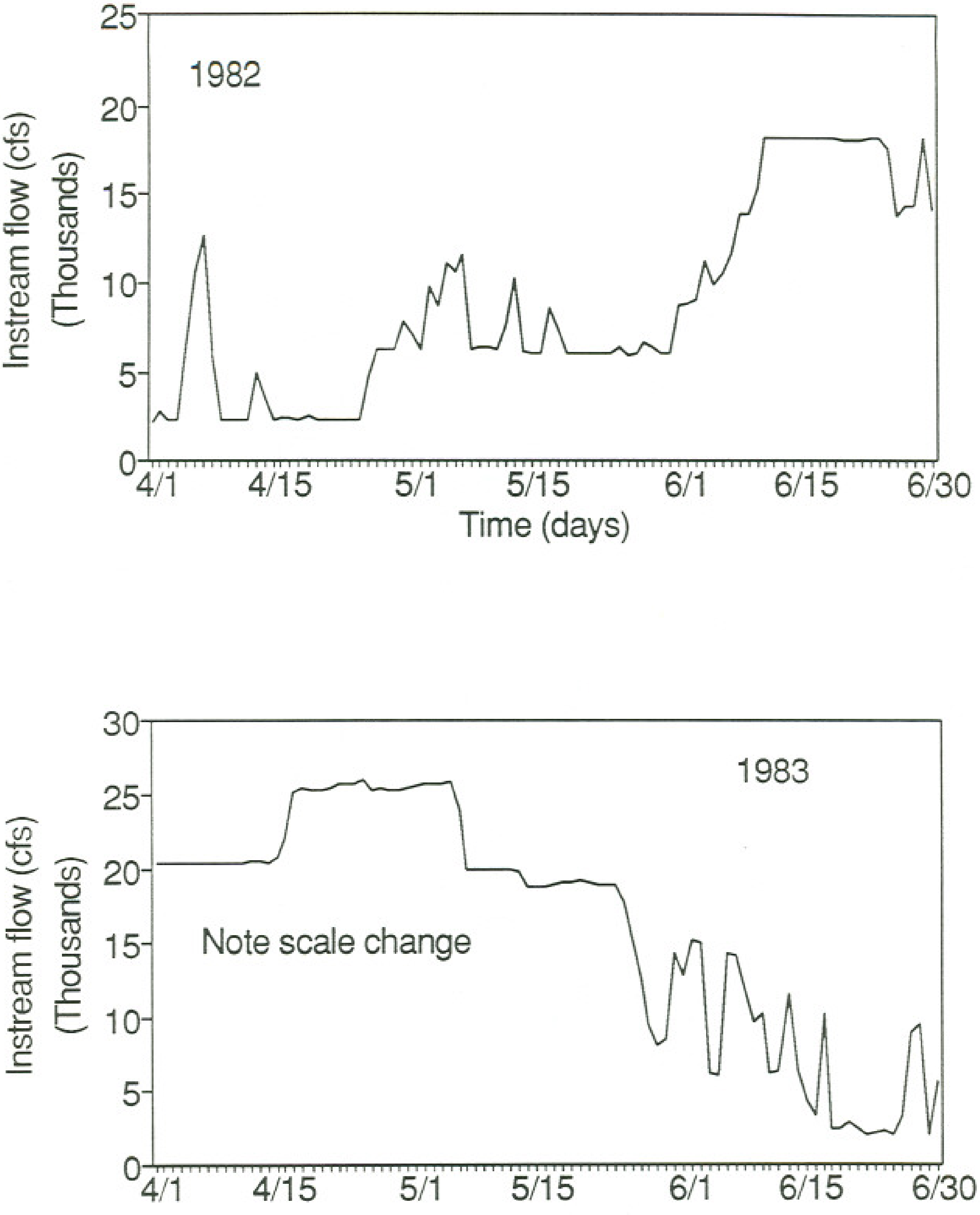
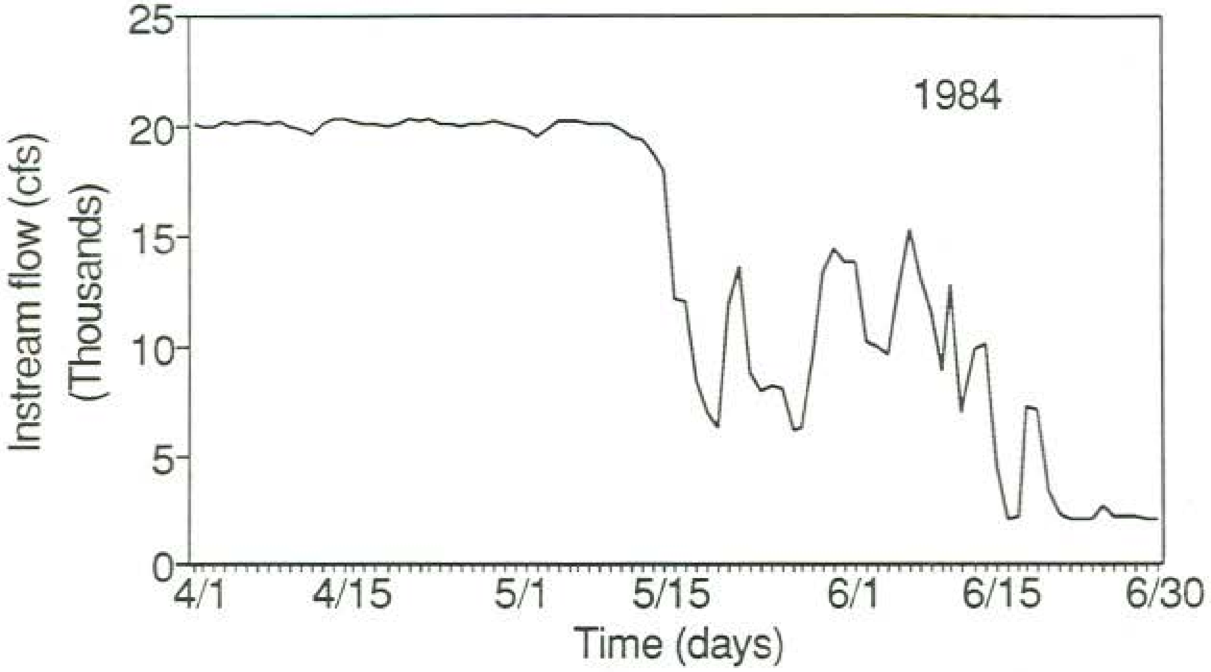


Figure 3. Average daily instream flow of the lower Roanoke River, North Carolina, for the period April through June 1982-1988 as recorded by U.S. Geological Survey gage at River Mile 133.6.



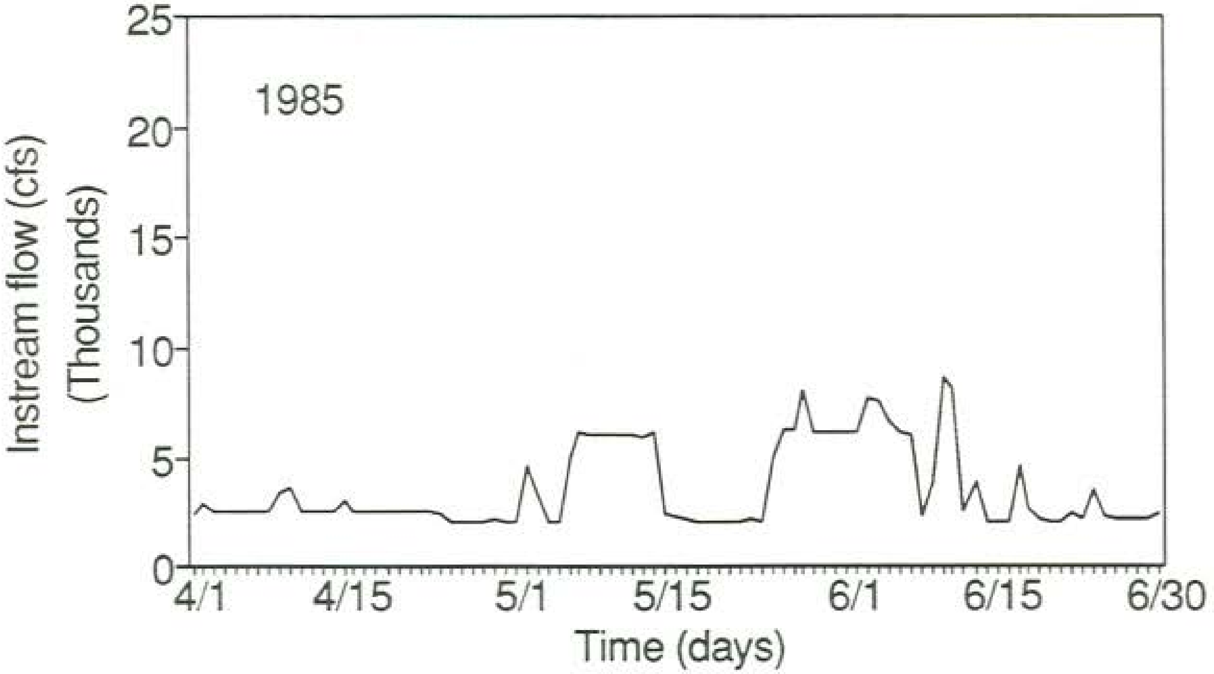
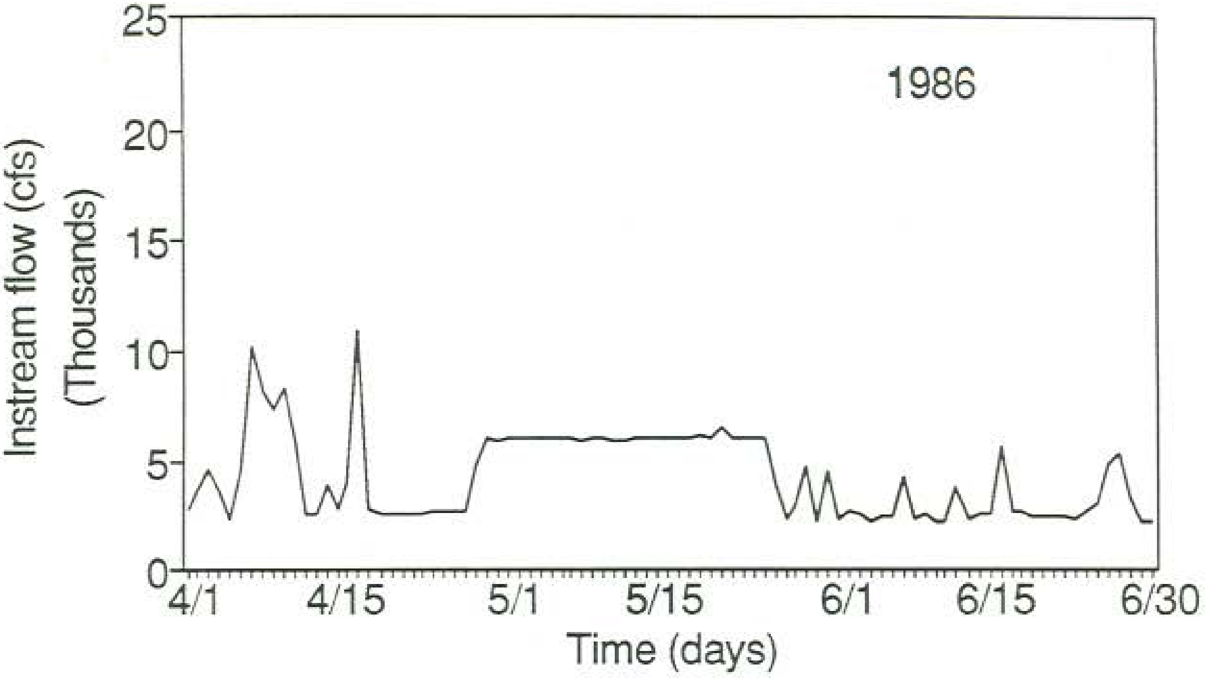


Figure 3. (Continued)



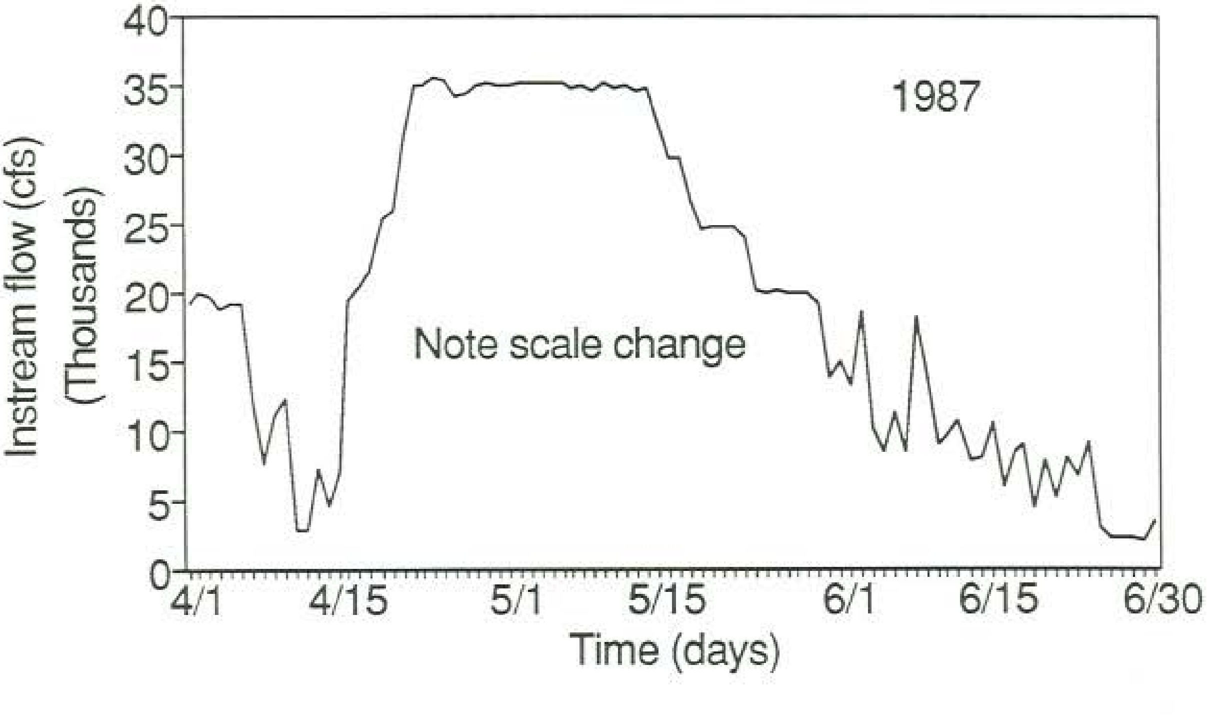


Figure 3. (Continued)

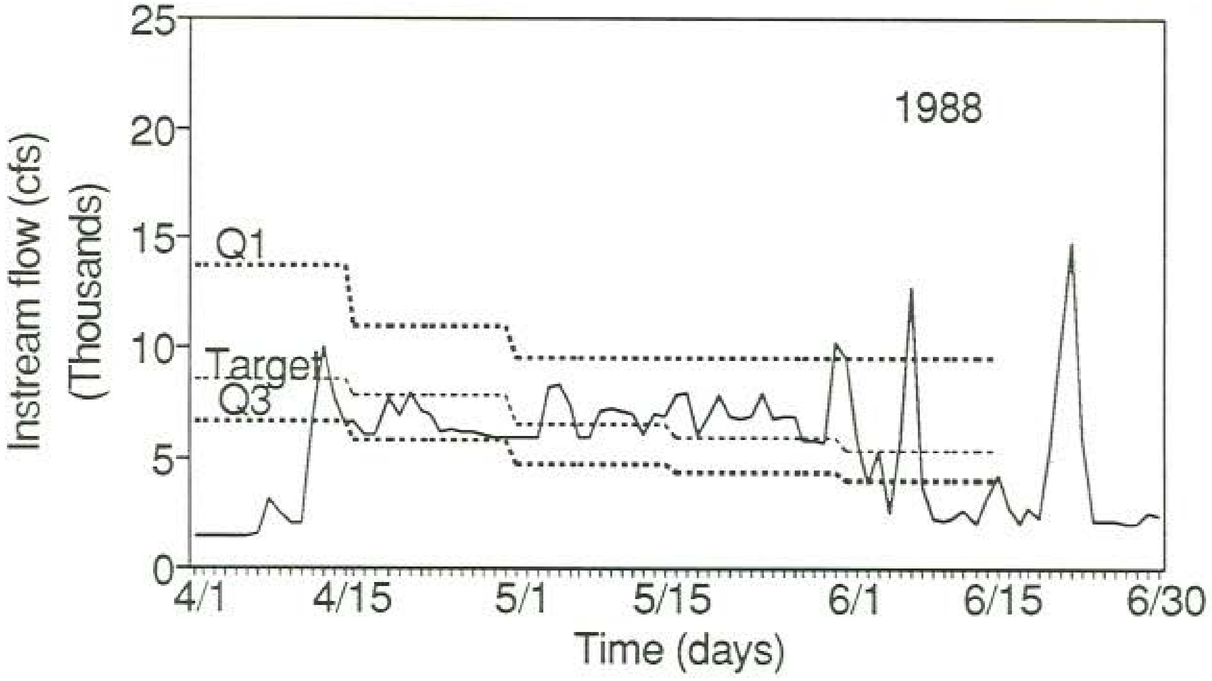
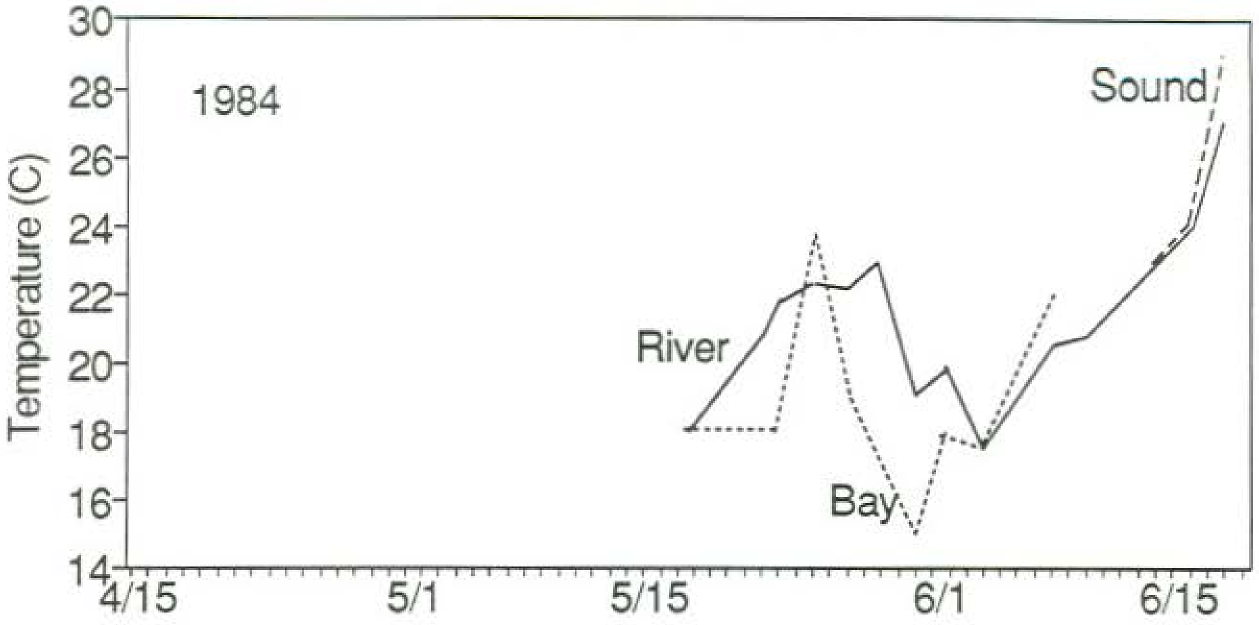


Figure 3. (Continued)



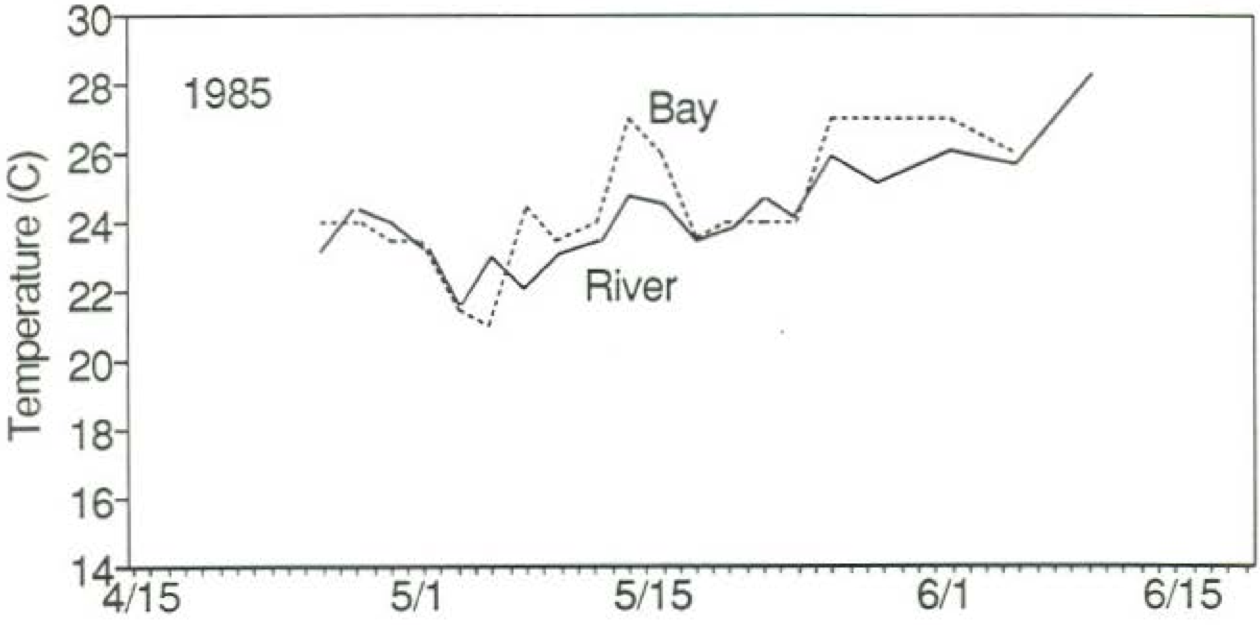
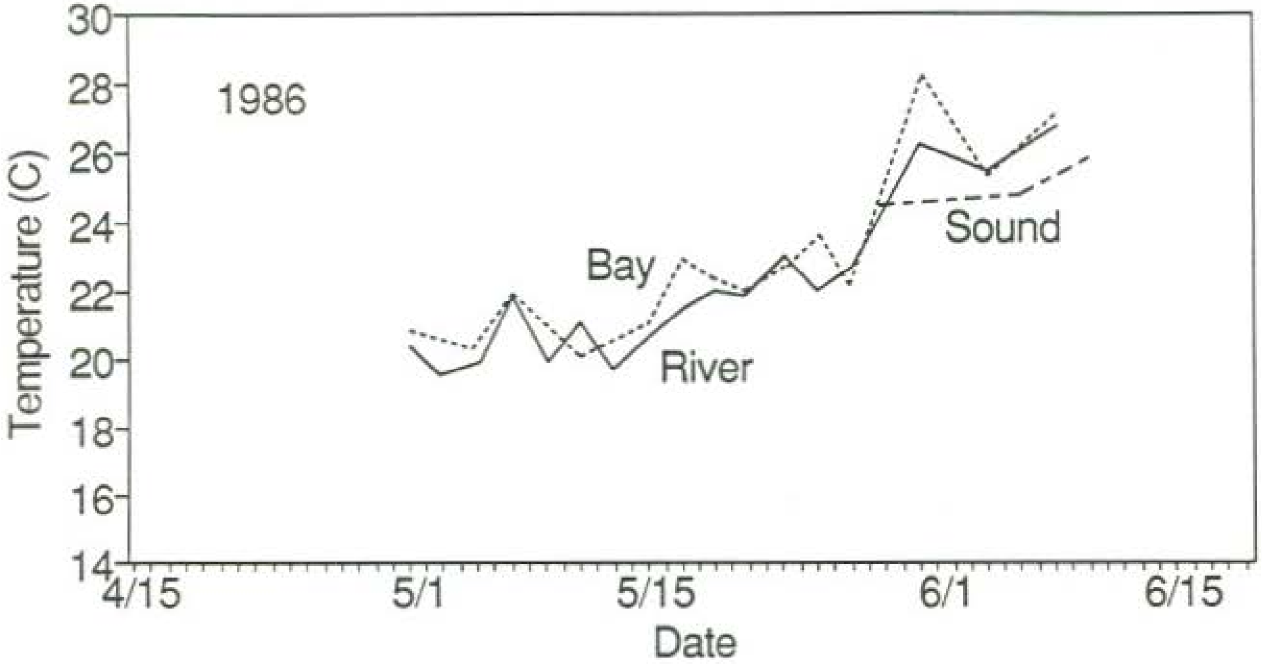
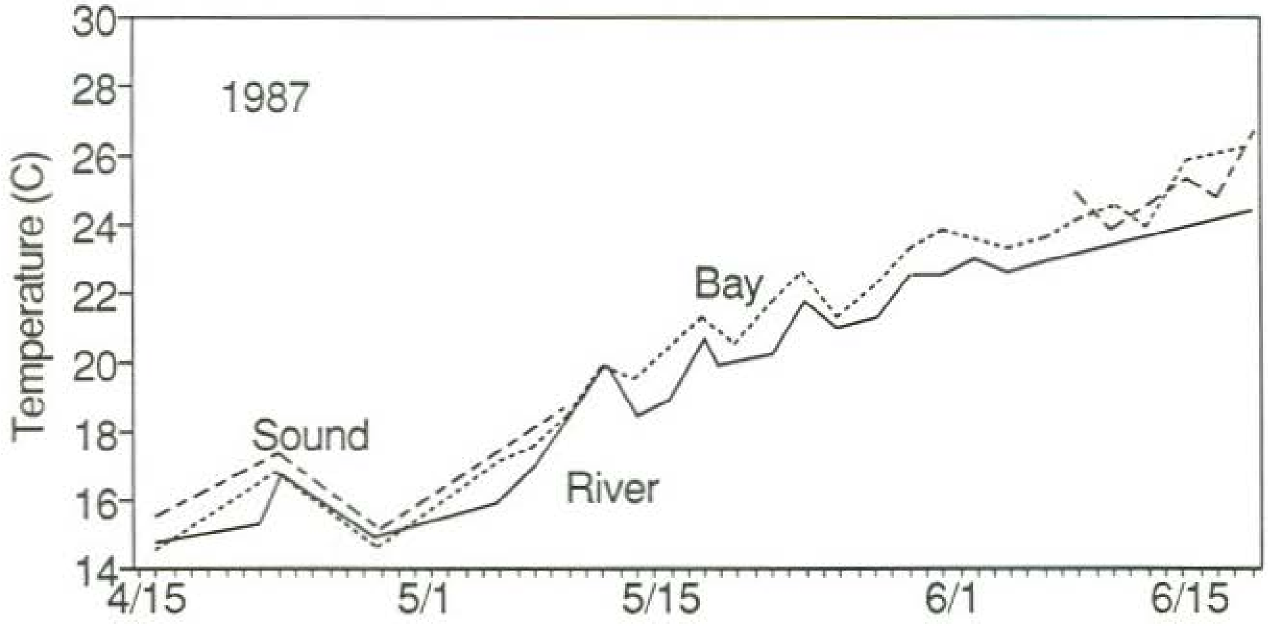


Figure 4. Average water temperature (°C), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1988.





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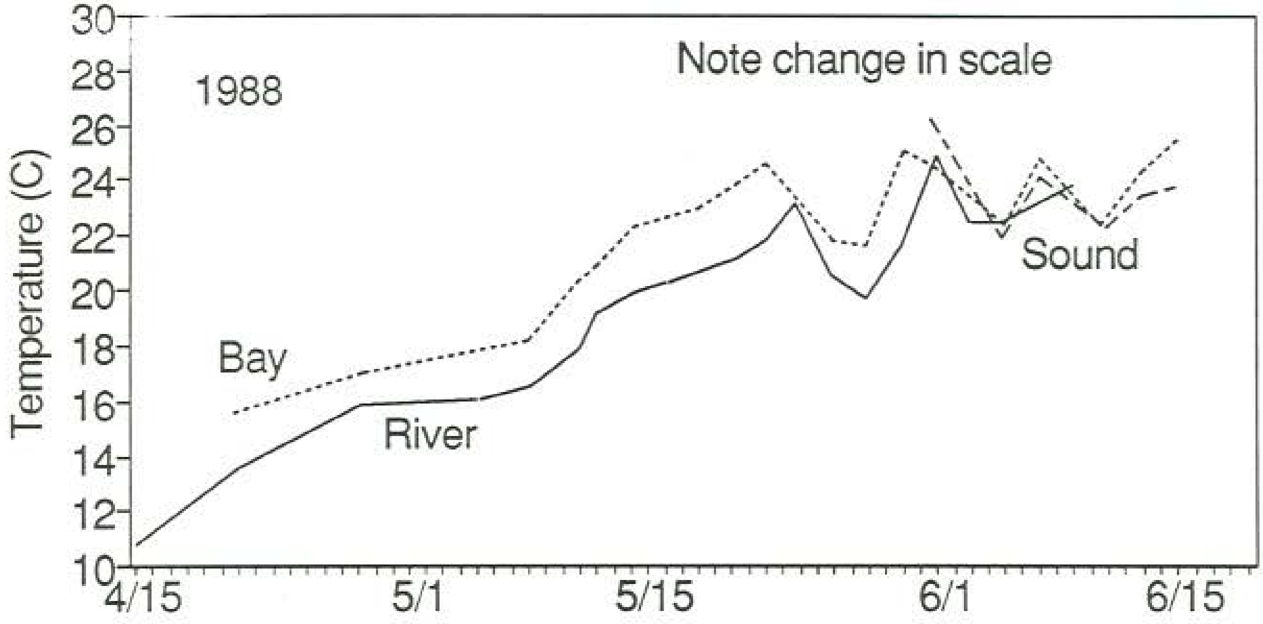

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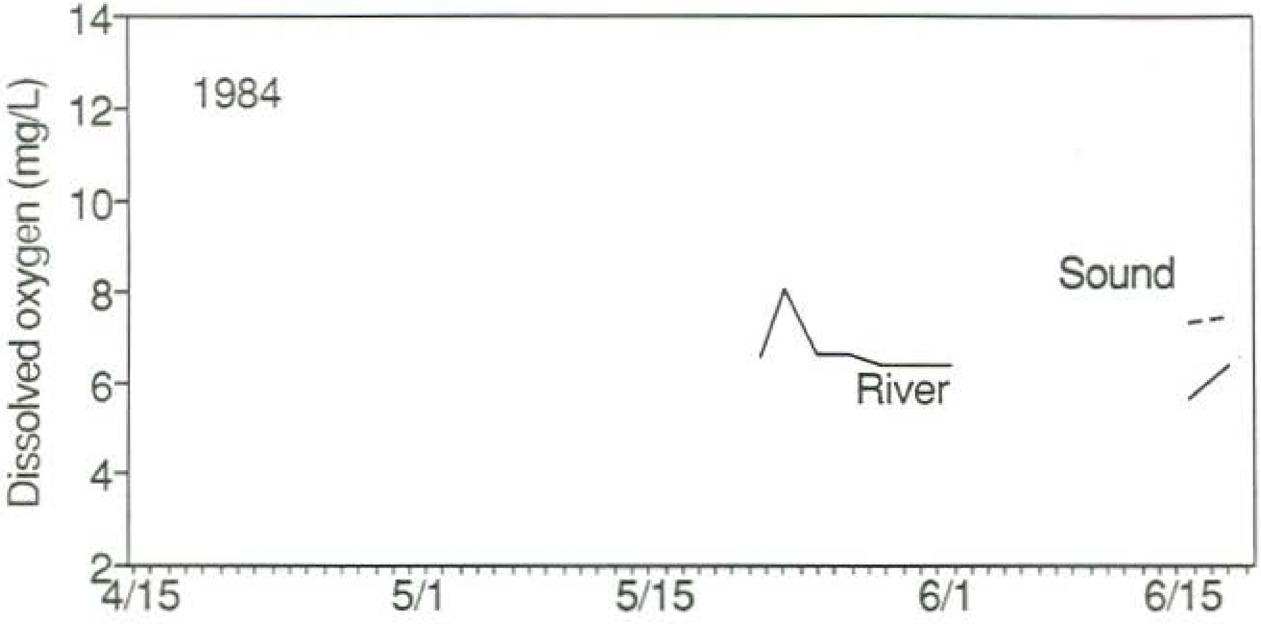


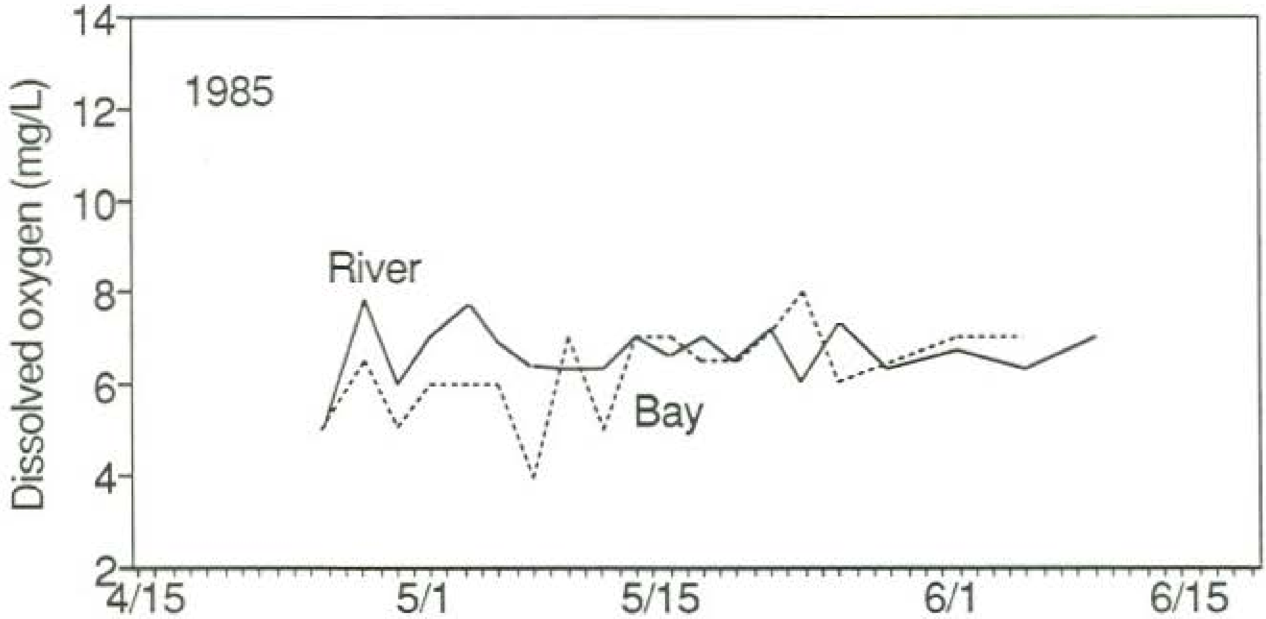
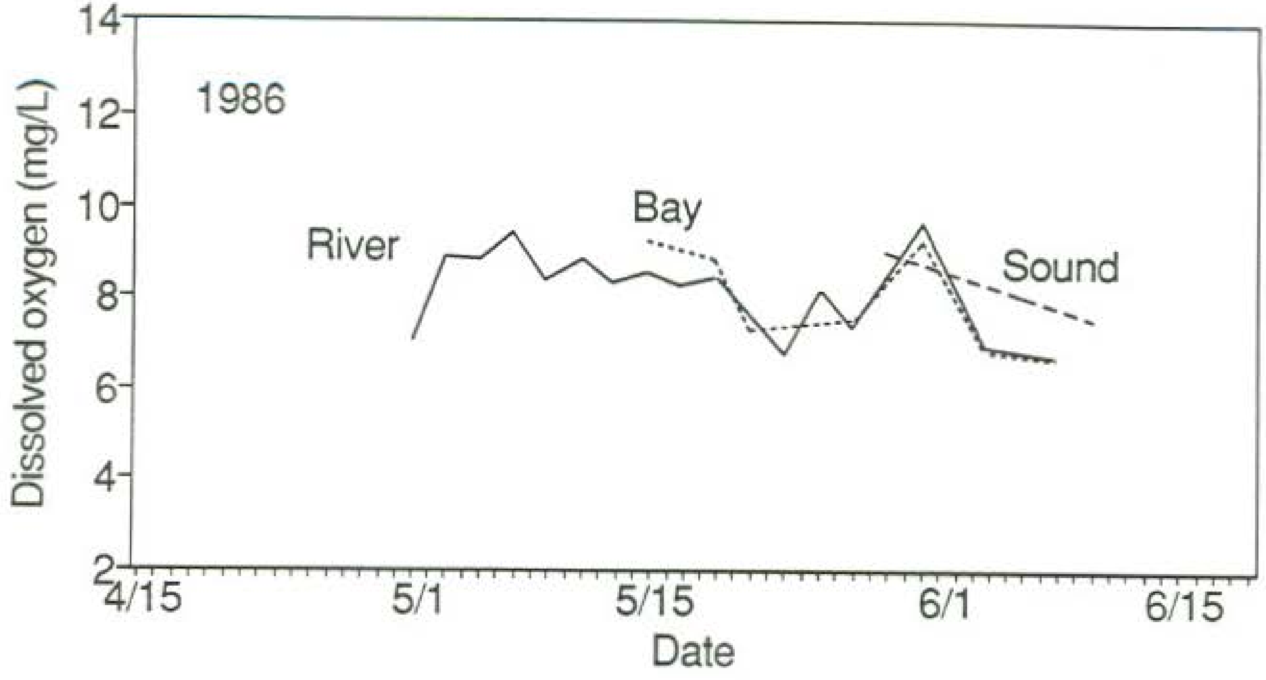
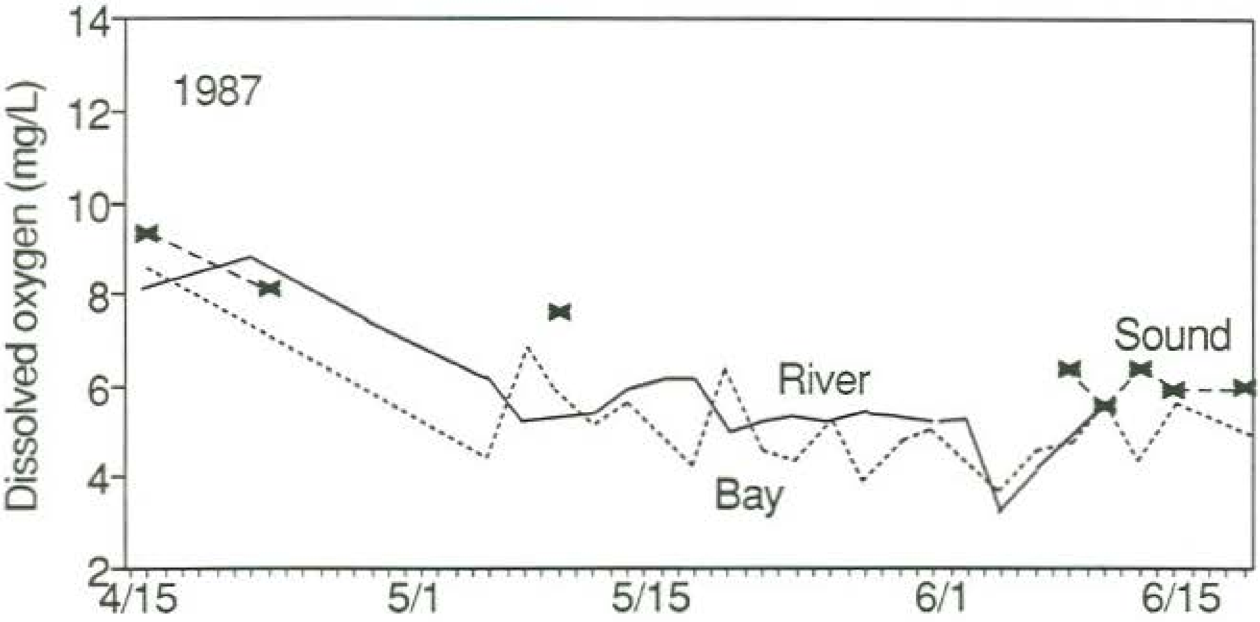


Figure 5. Average dissolved oxygen levels (mg/L), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1988.





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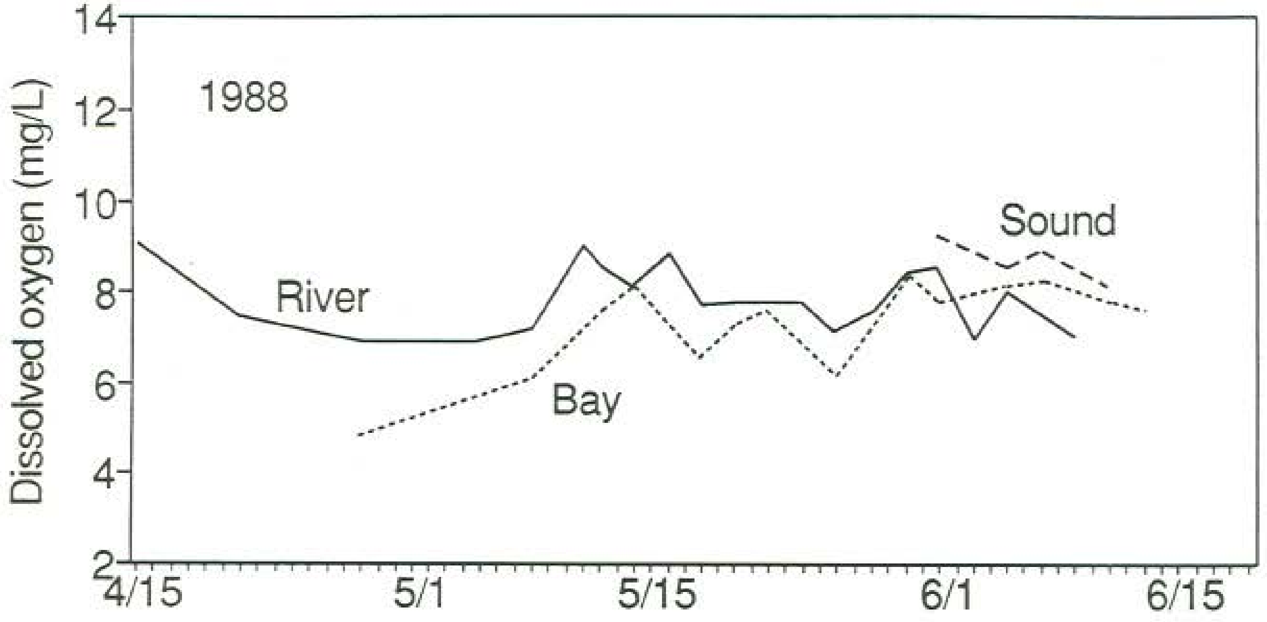

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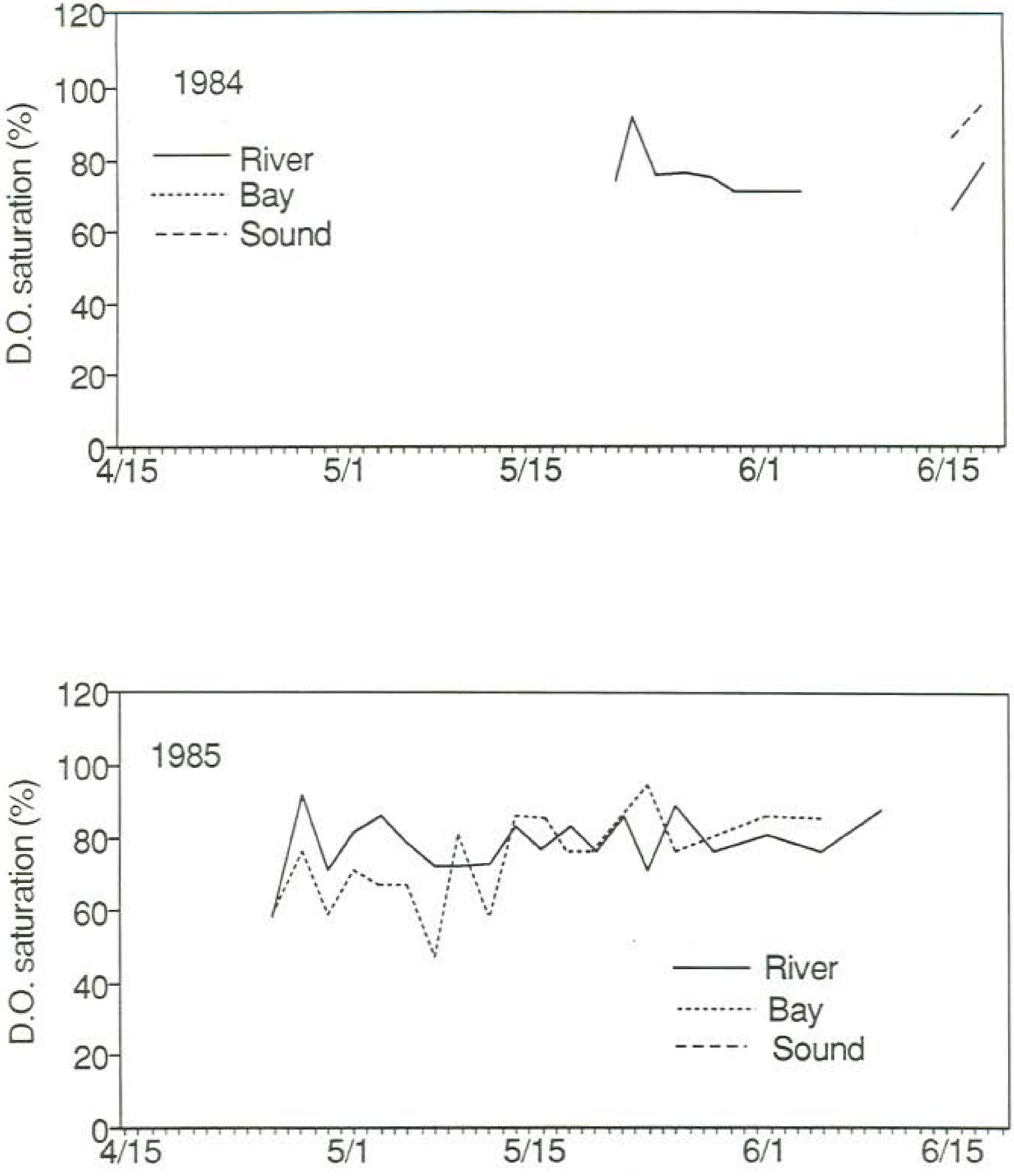
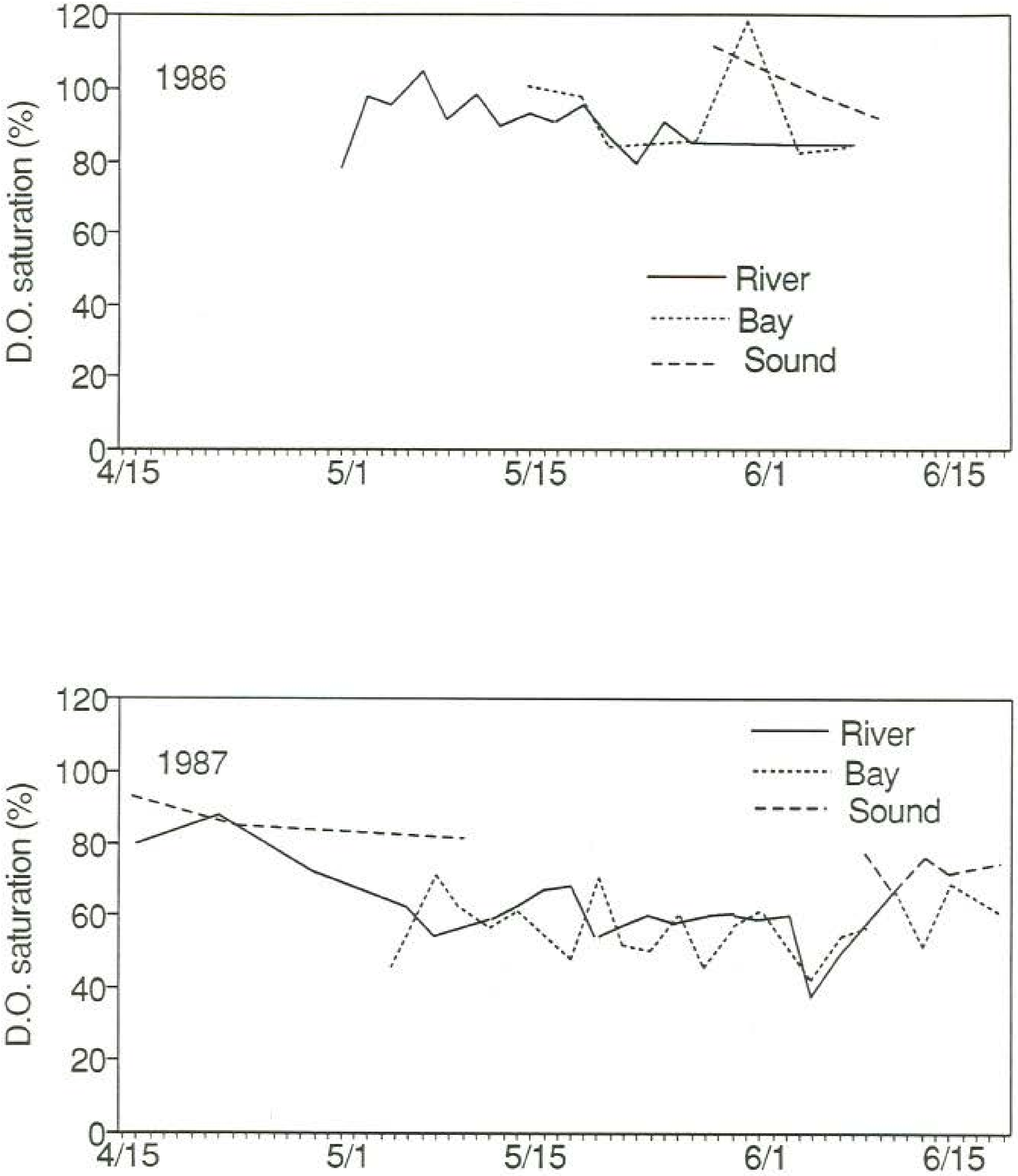


Figure 6. Average dissolved oxygen saturation (%), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1988.



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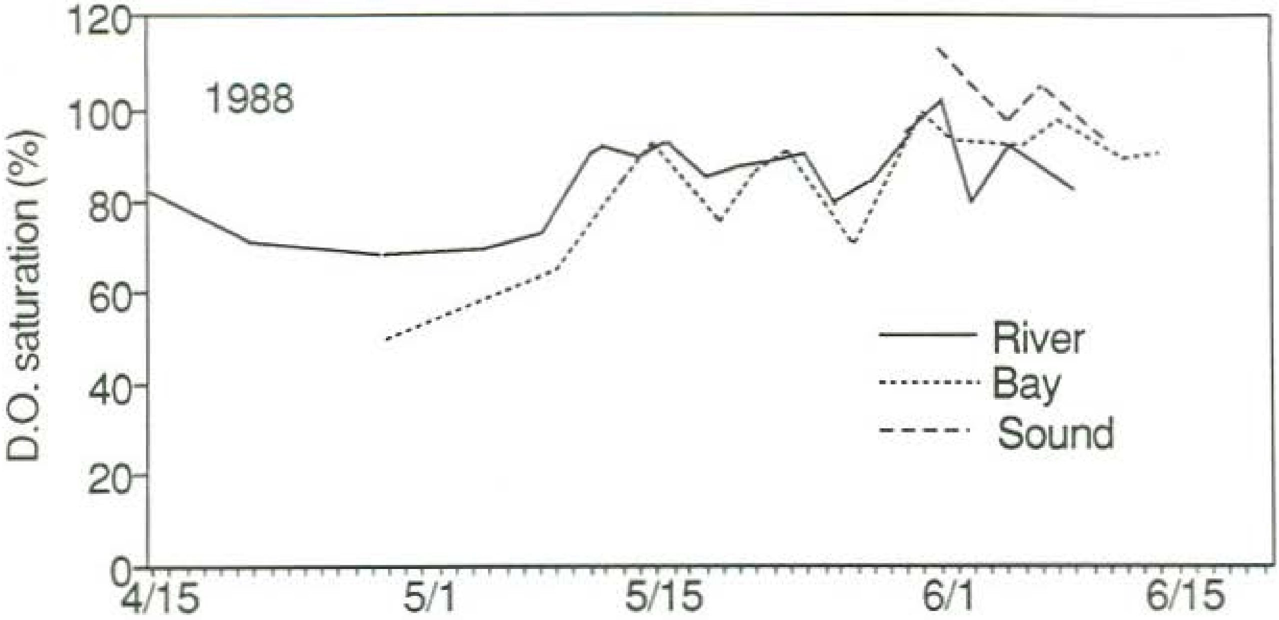

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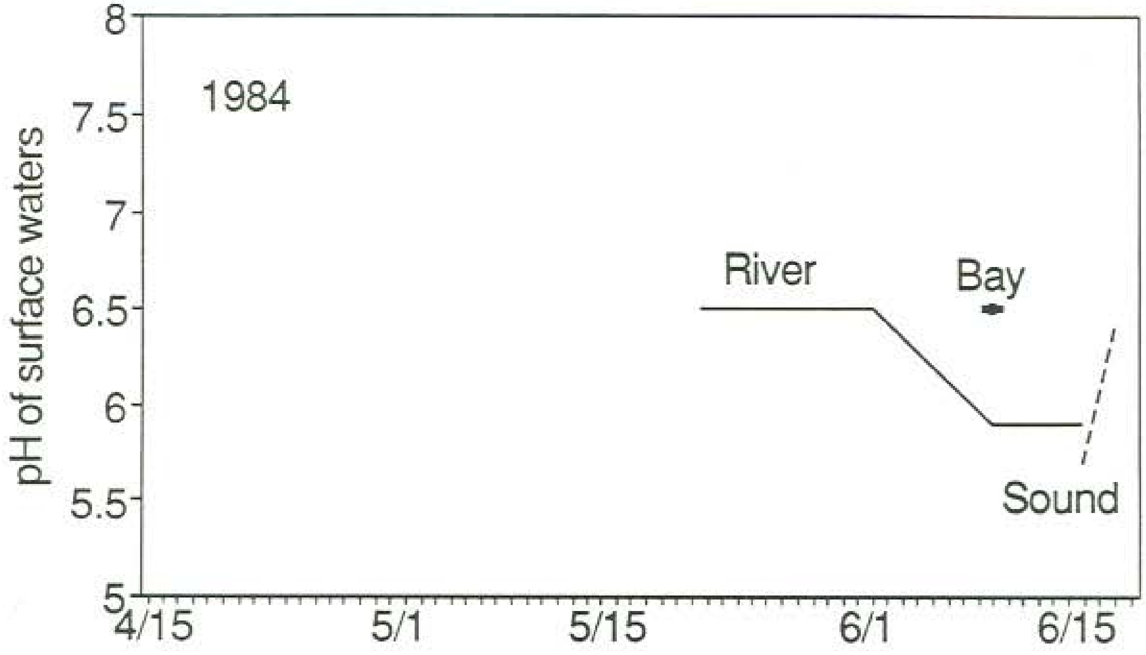


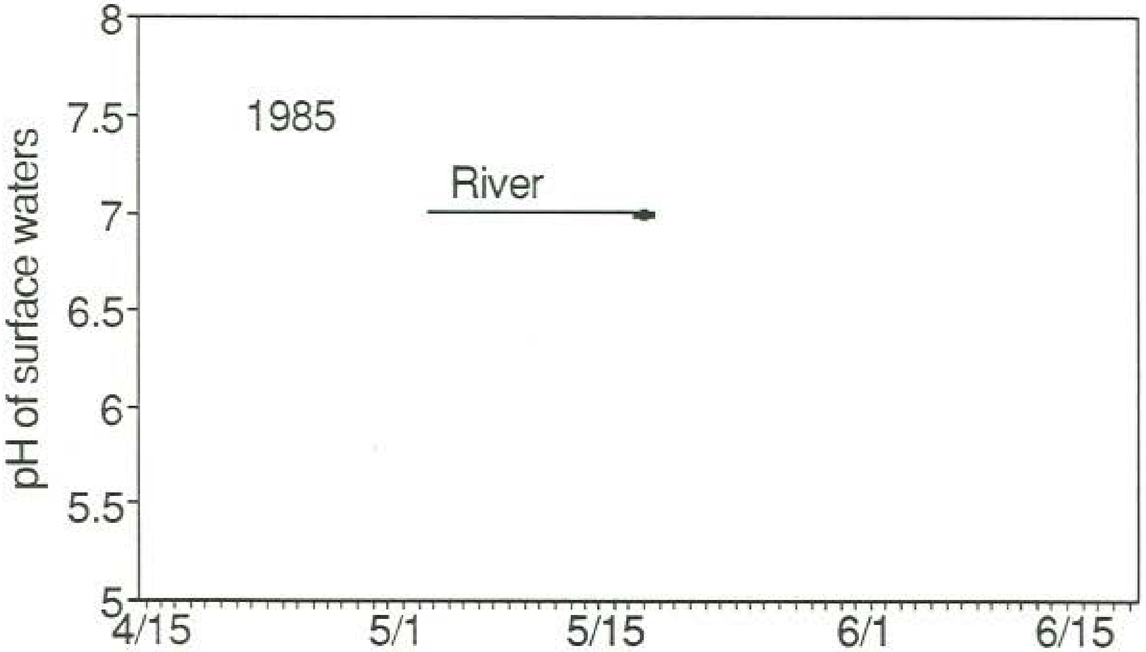
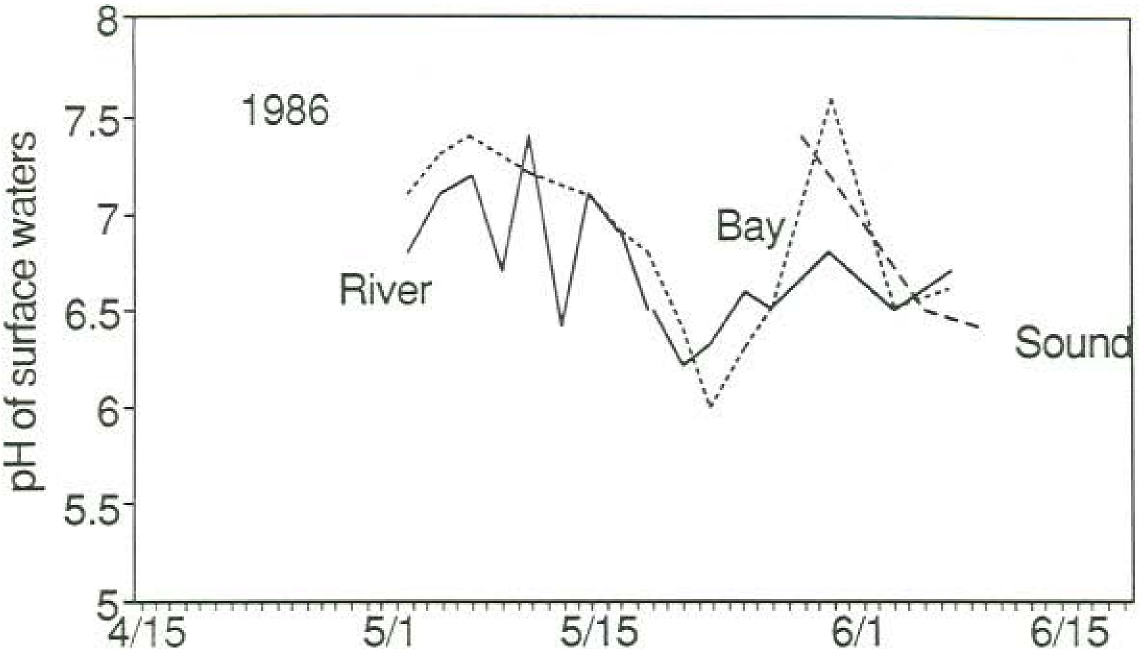
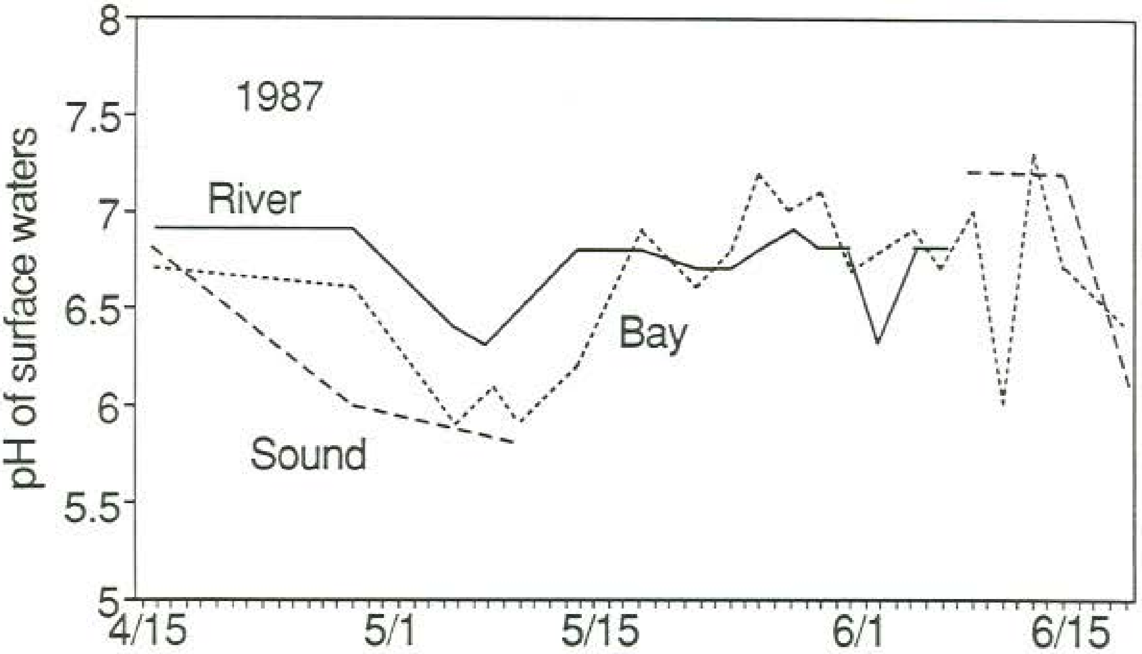


Figure 7. Average surface water pH, by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1988.





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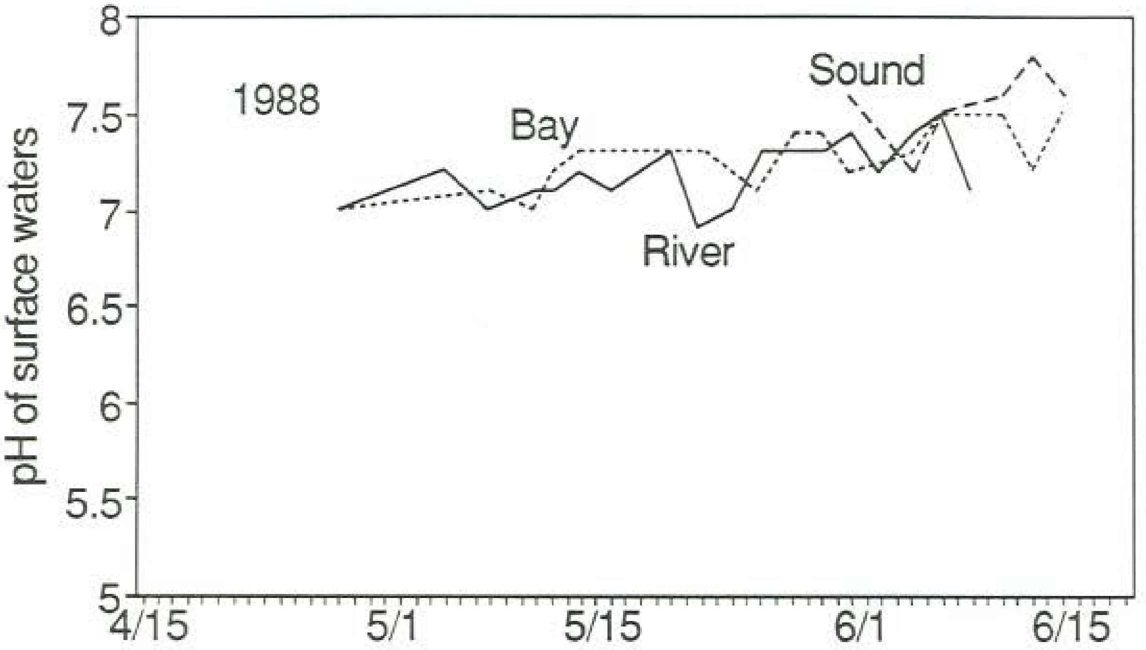

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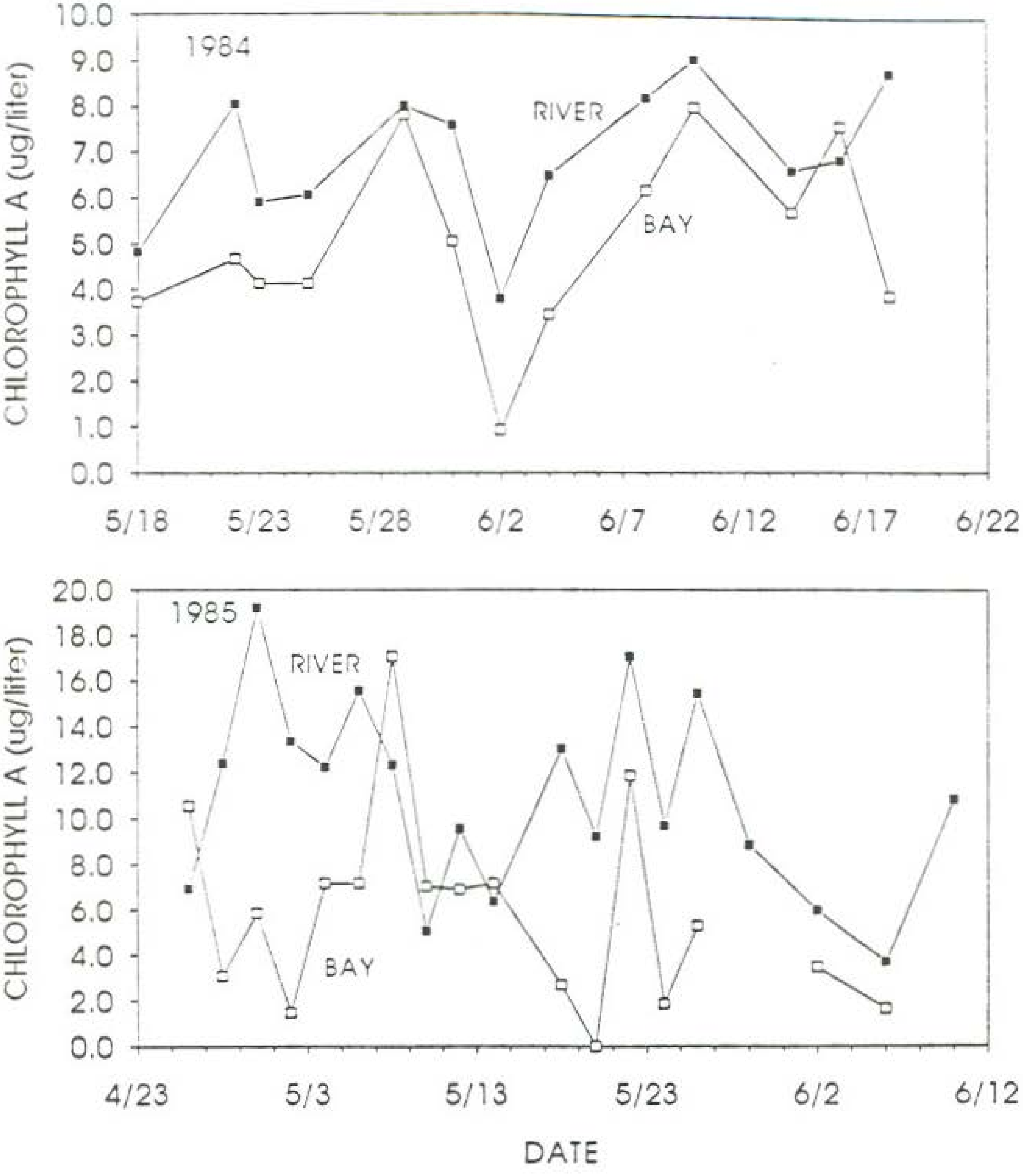
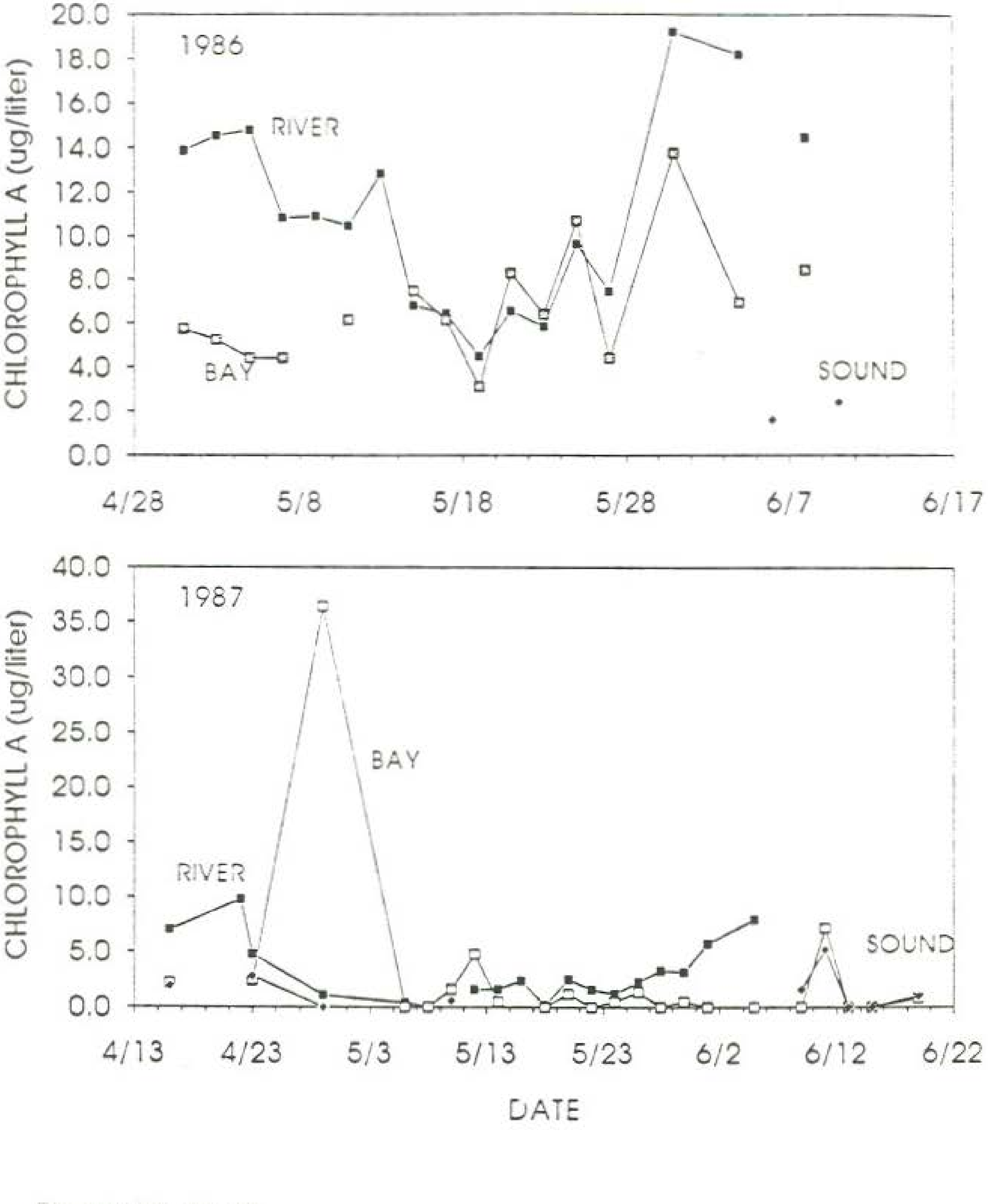


Figure 8. Average values of chlorophyll *a* (µg/L), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1988.



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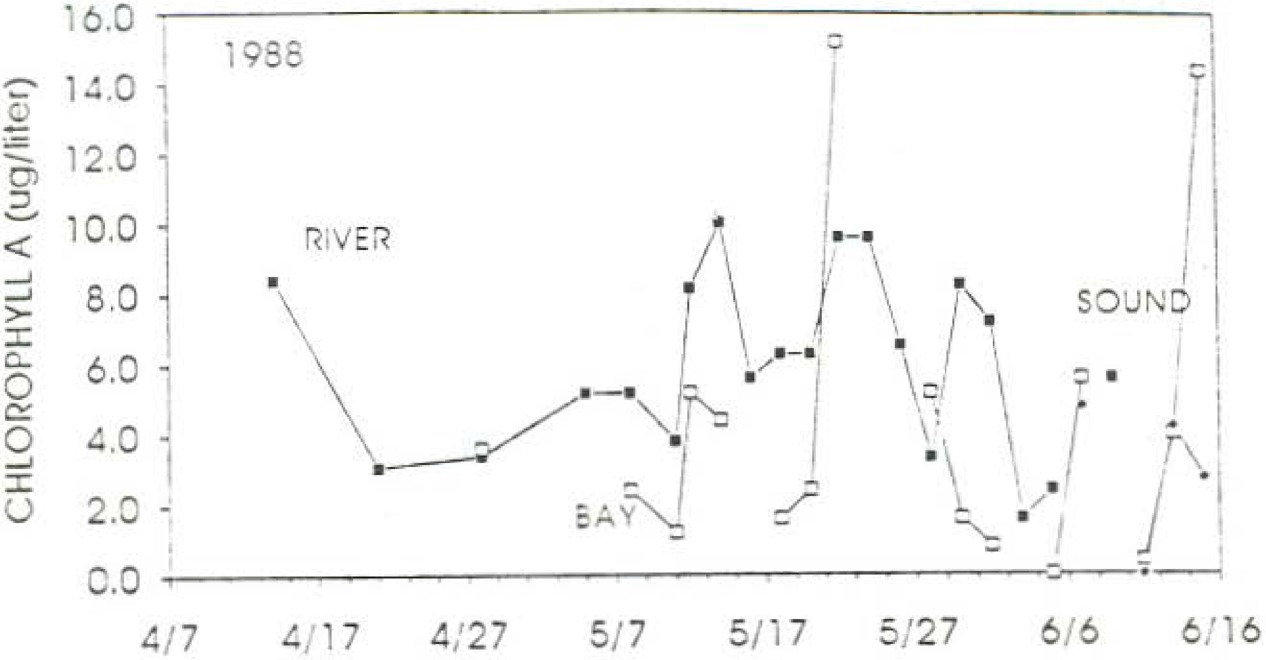

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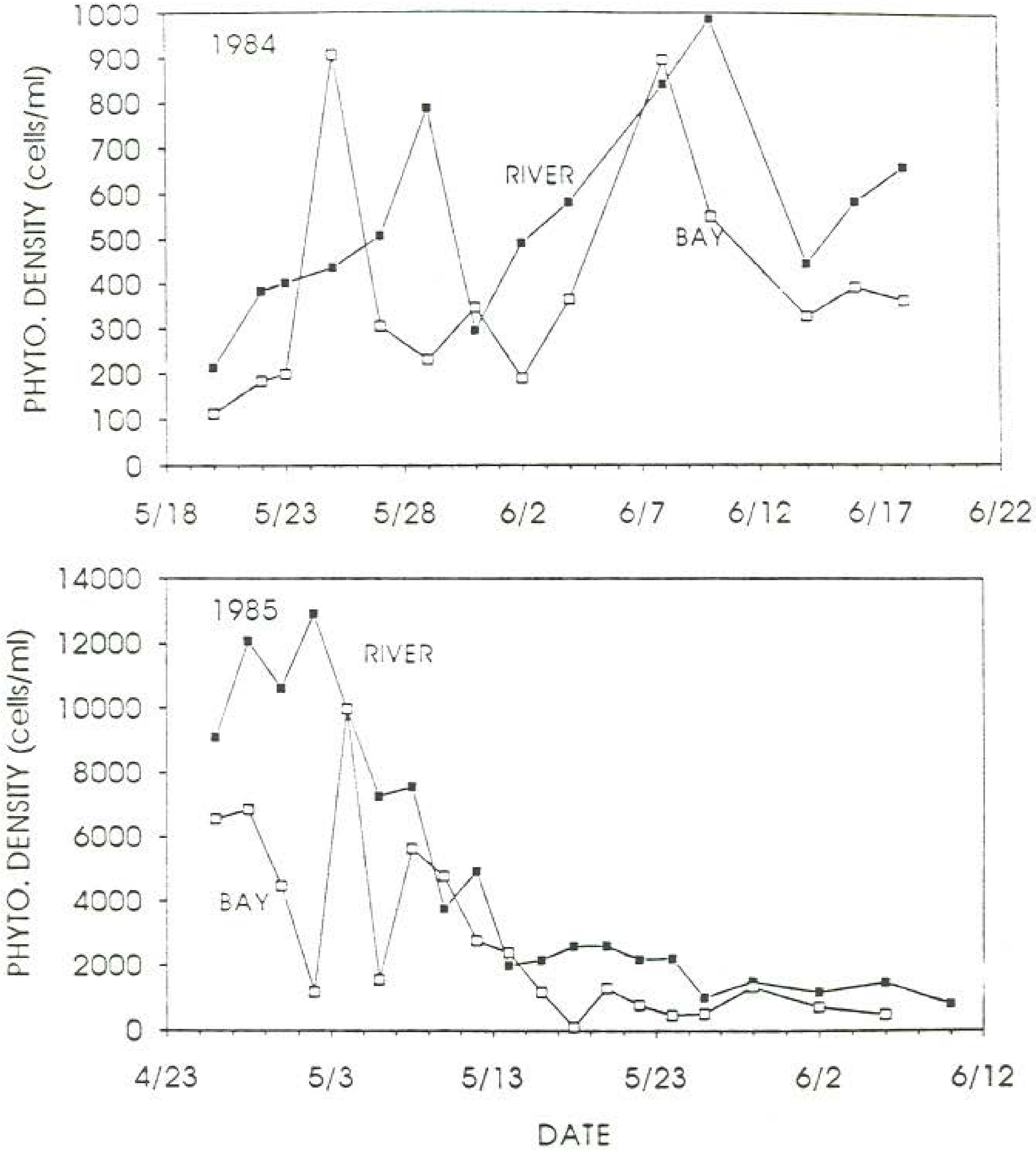
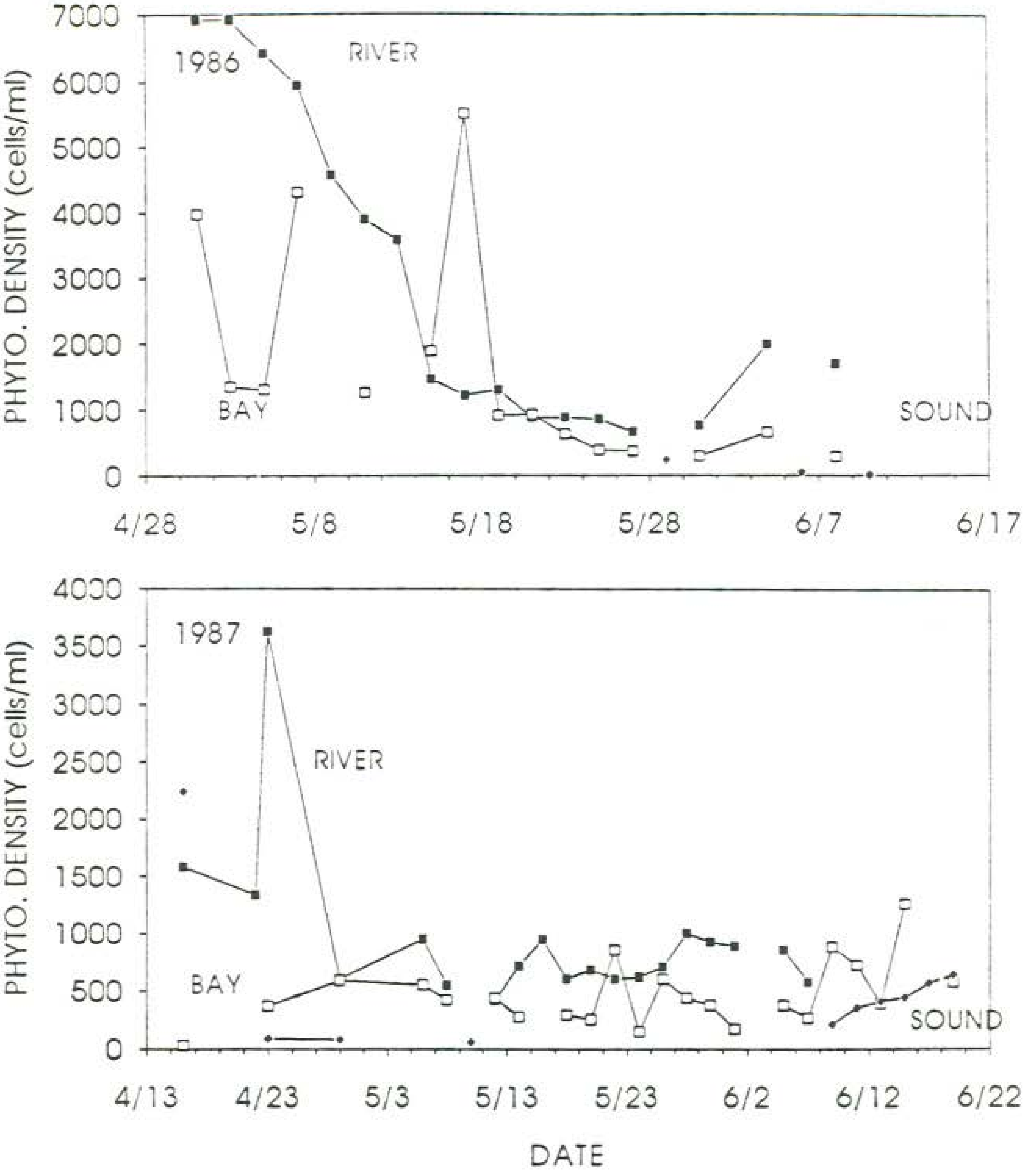


Figure 9. Average phytoplankton density (cells/ml), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1988j.



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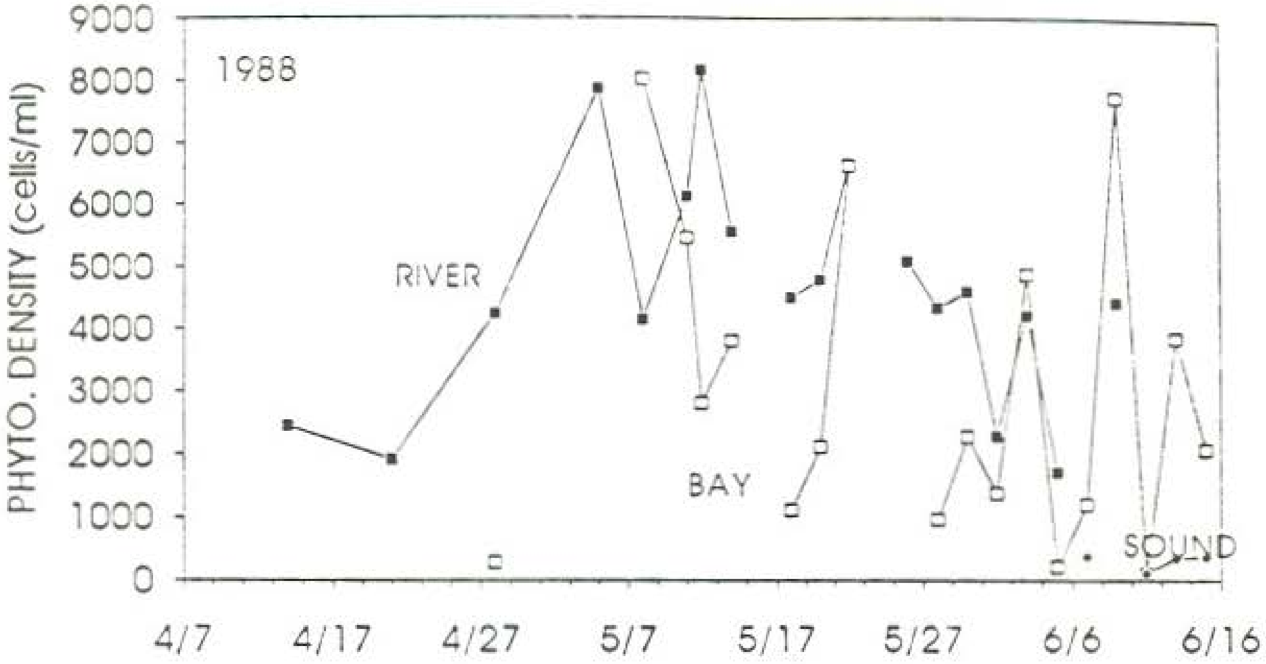

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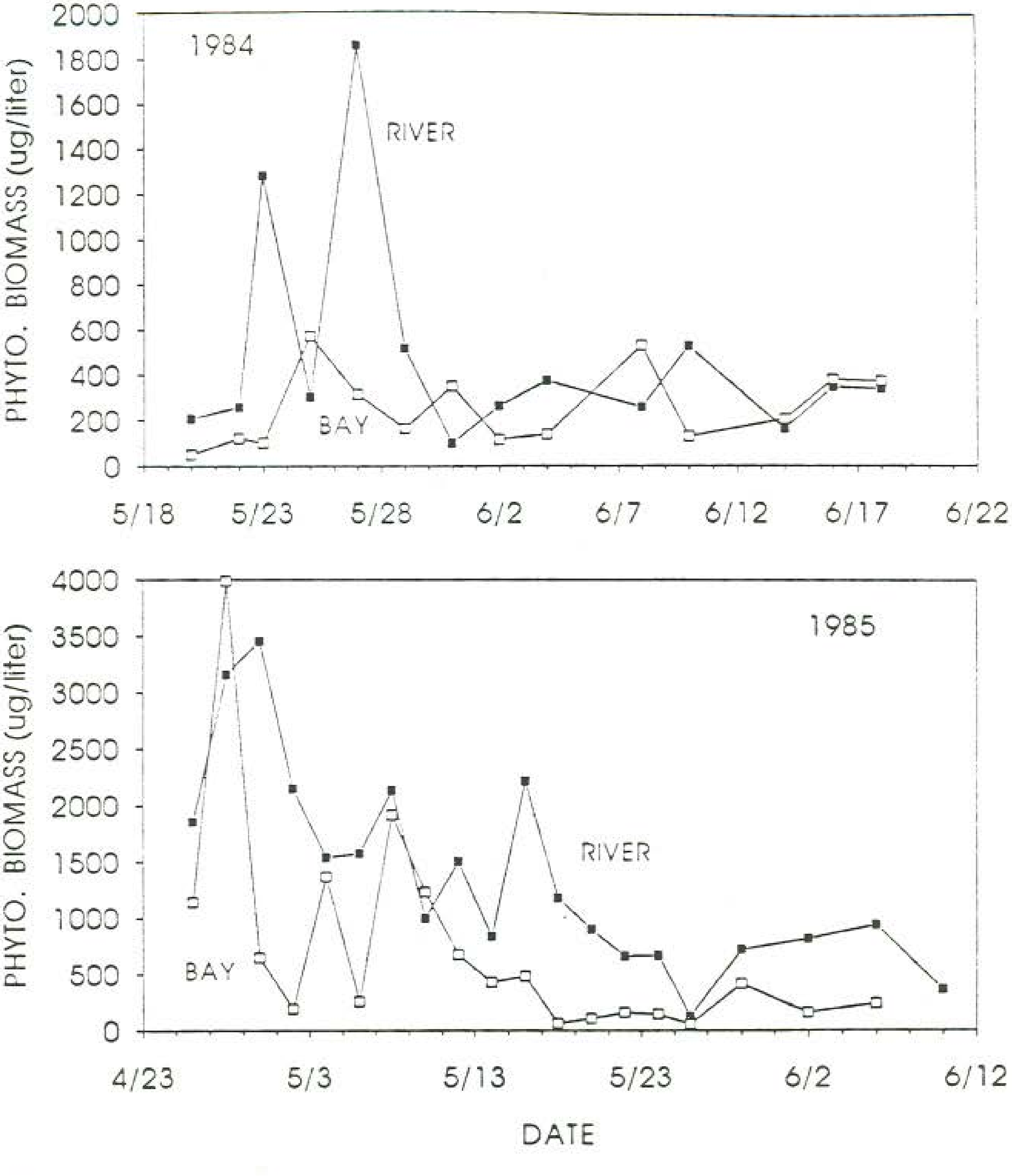
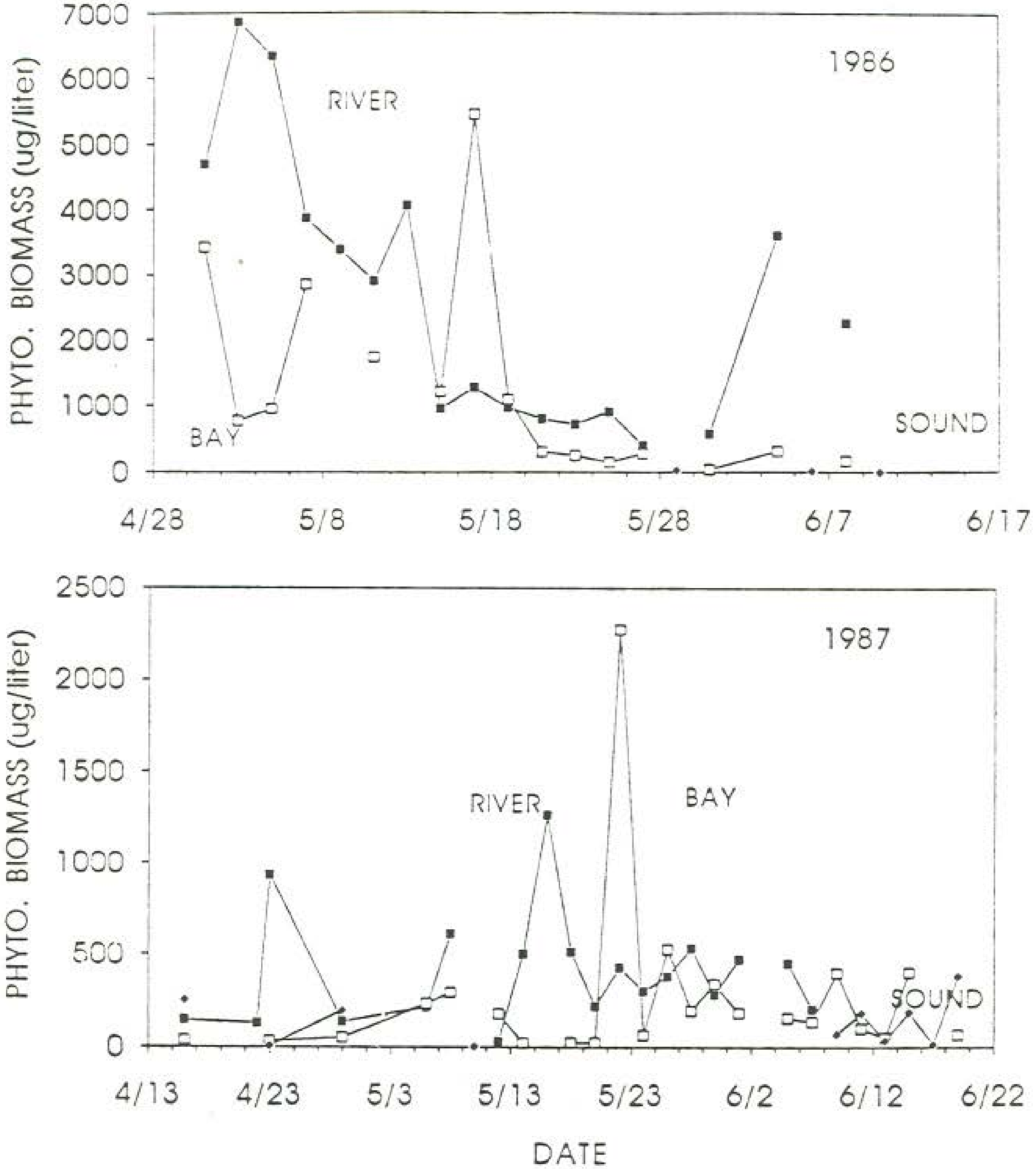


Figure 10. Average phytoplankton biomass (µg/L), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1988.



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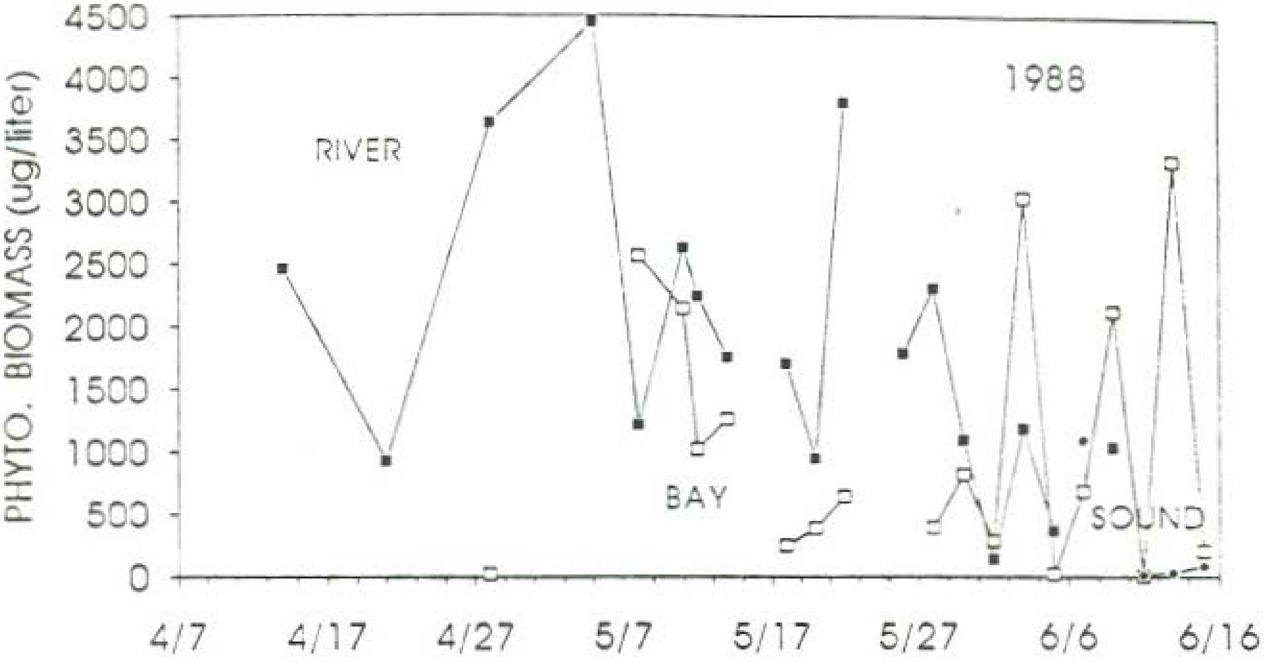


Figure 10. (Continued)

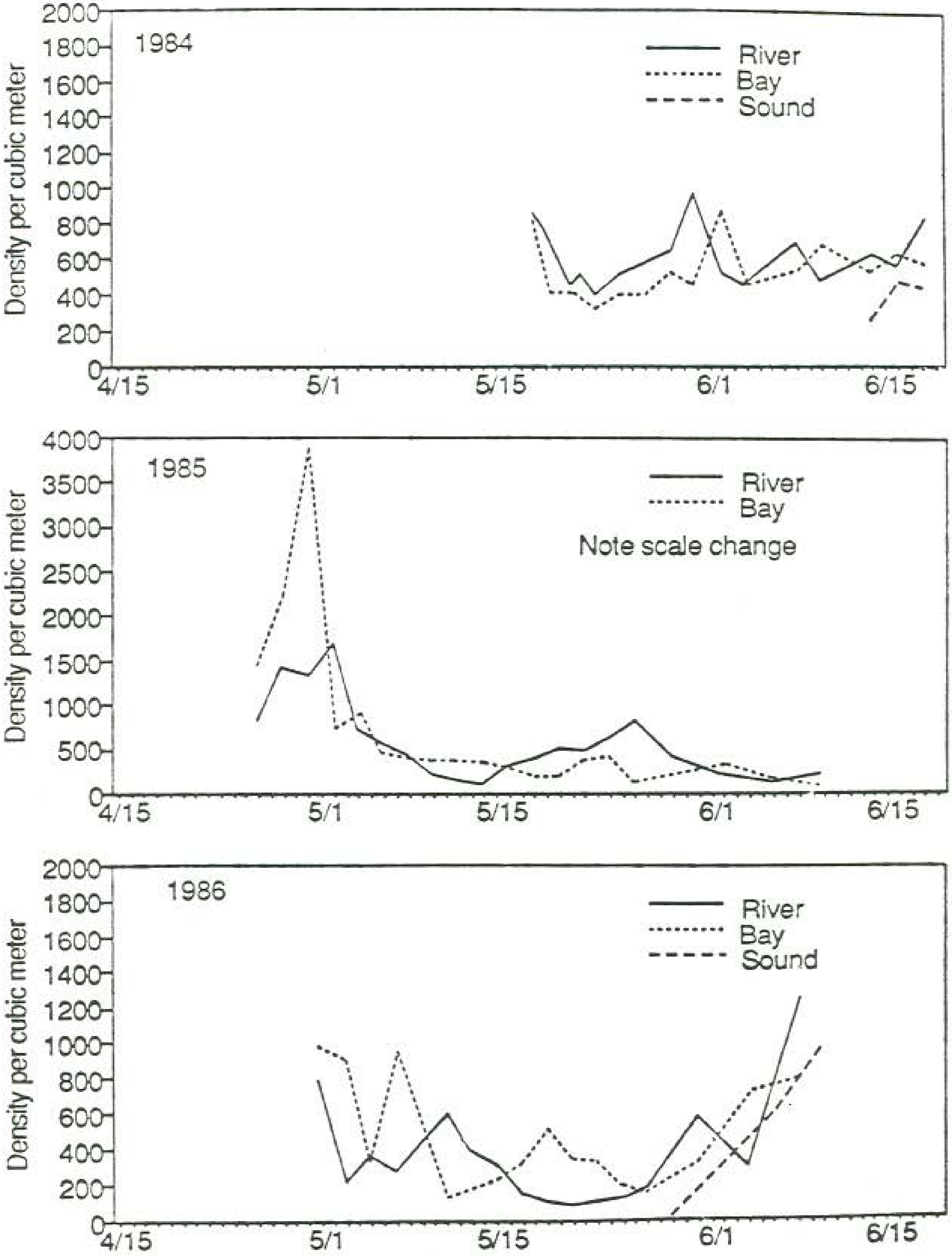
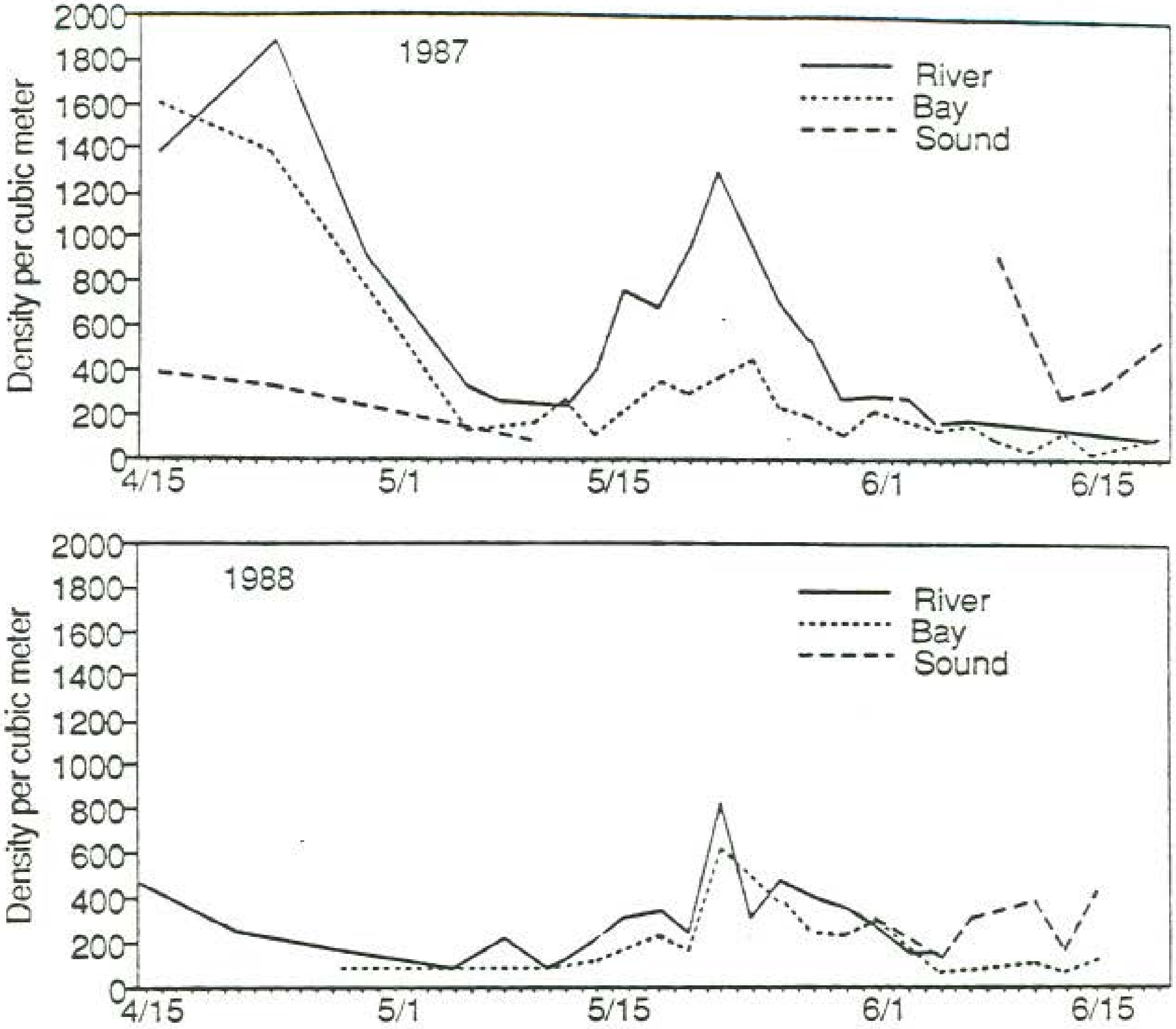


Figure 11. Average zooplankton density (number/m^3), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) for the period 1984-1988.



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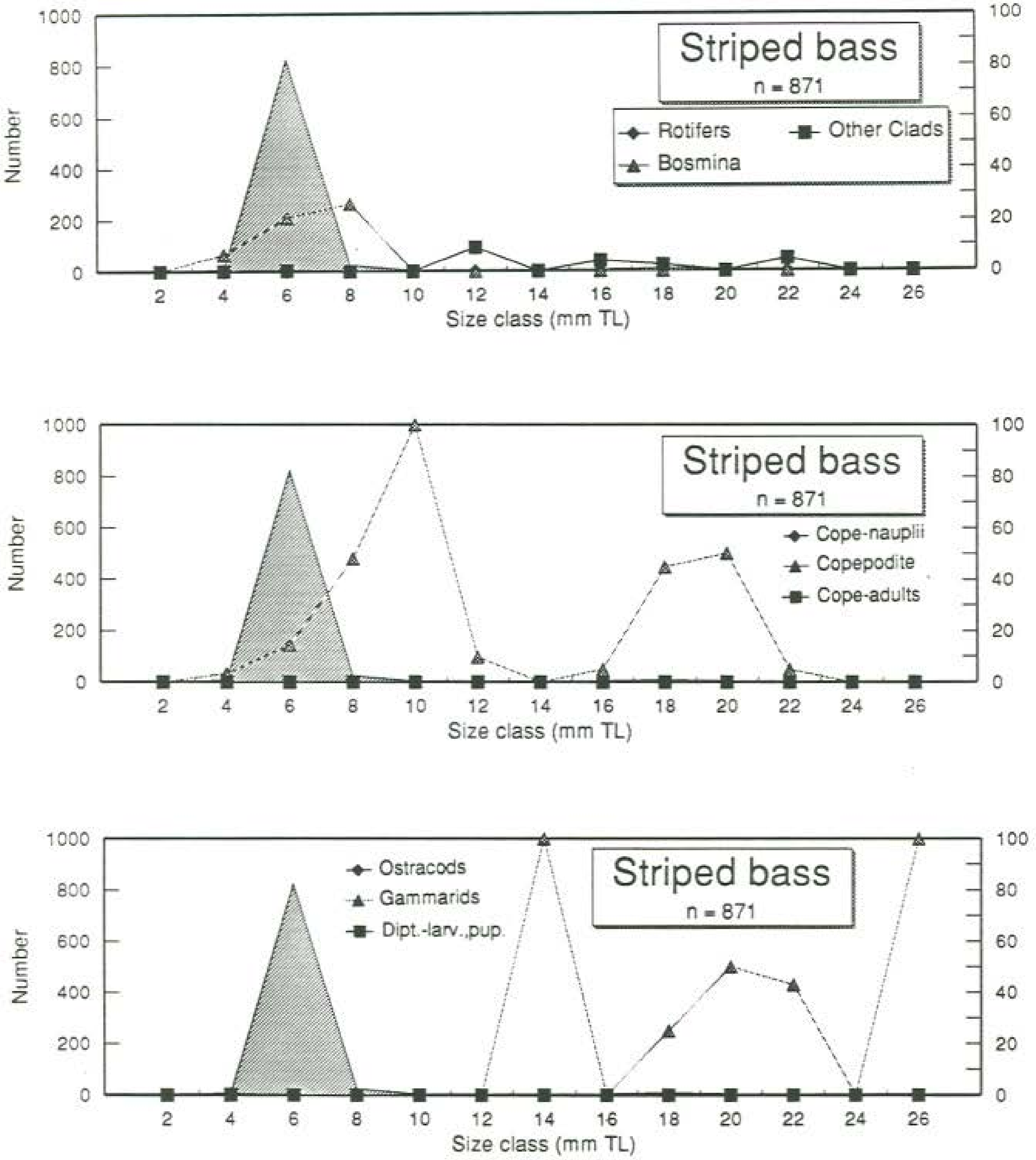

Figure 12. The number of young striped bass examined by size class (shaded area), and the average relative biomass (%) of prey in fish stomachs within a size class.

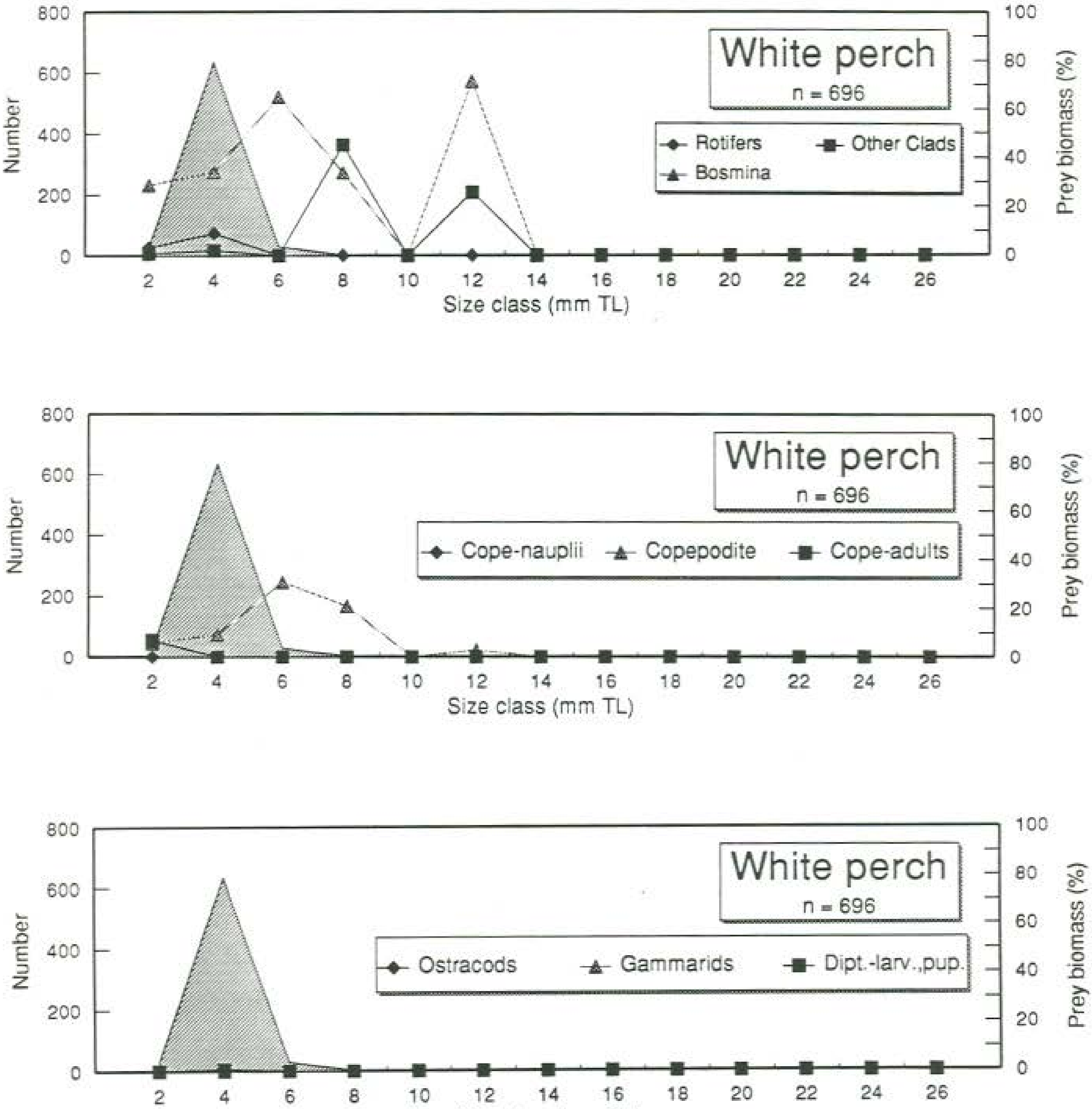

Figure 13. The number of young white perch examined by size class (shaded area), and the average relative biomass (%) of prey in fish stomachs within a size class.

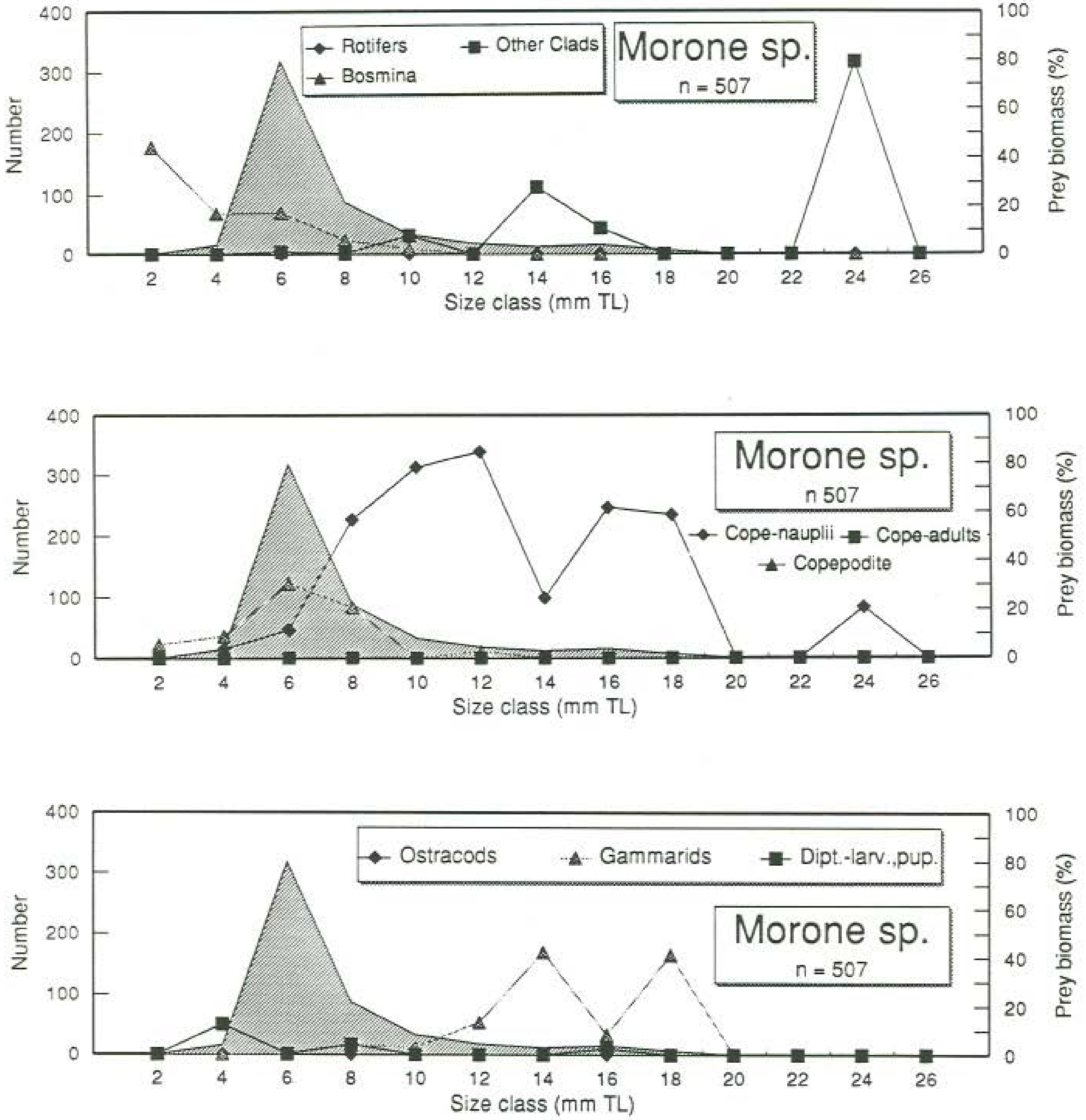

Figure 14. The number of young unidentified *Morone* species examined by size class (shaded area), and the average relative biomass (%) of prey in fish stomachs within a size class.

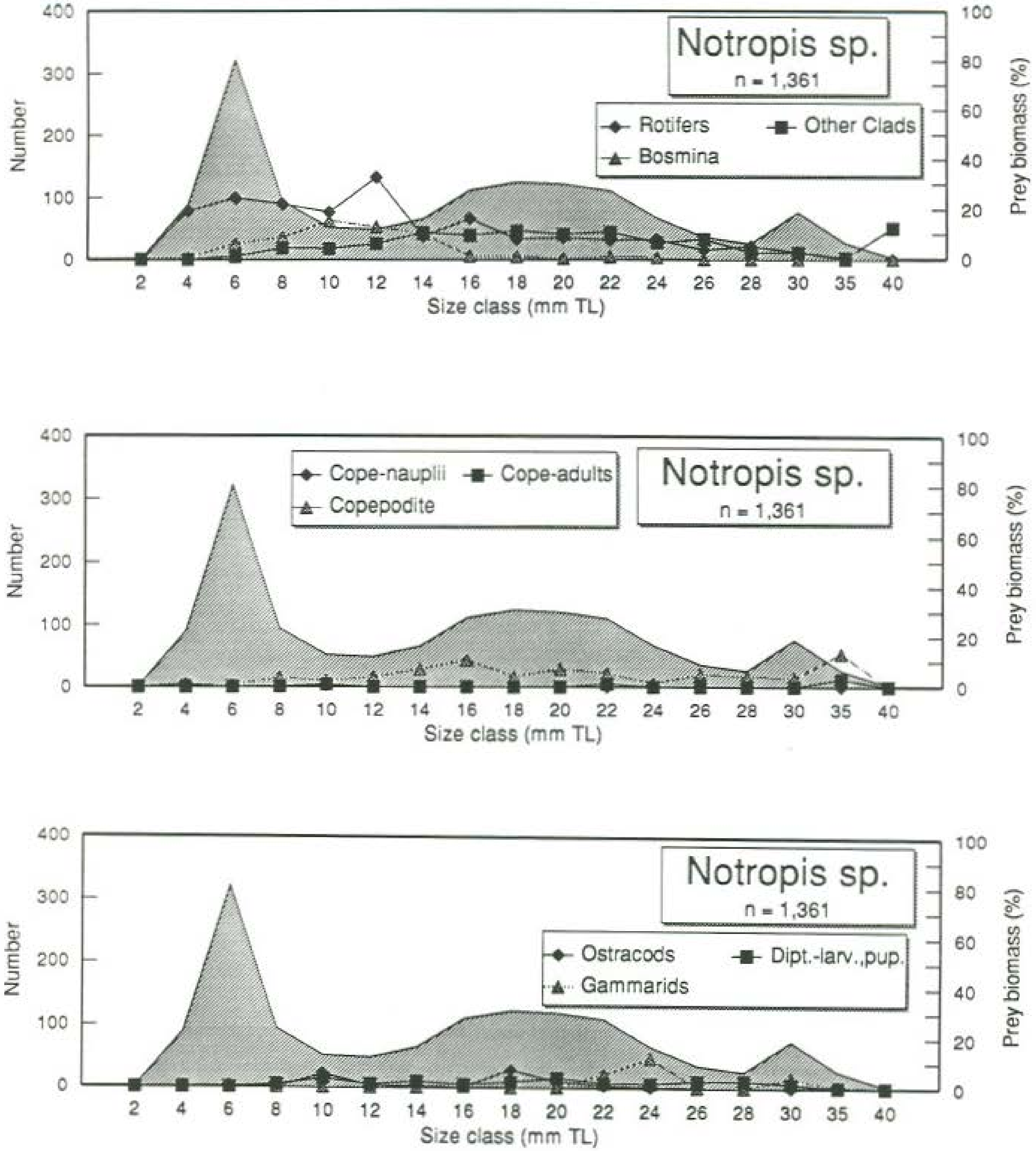

Figure 15. The number of young *Notropis* (minnow) species examined by size class (shaded area), and the average relative biomass (%) of prey in fish stomachs within a size class.

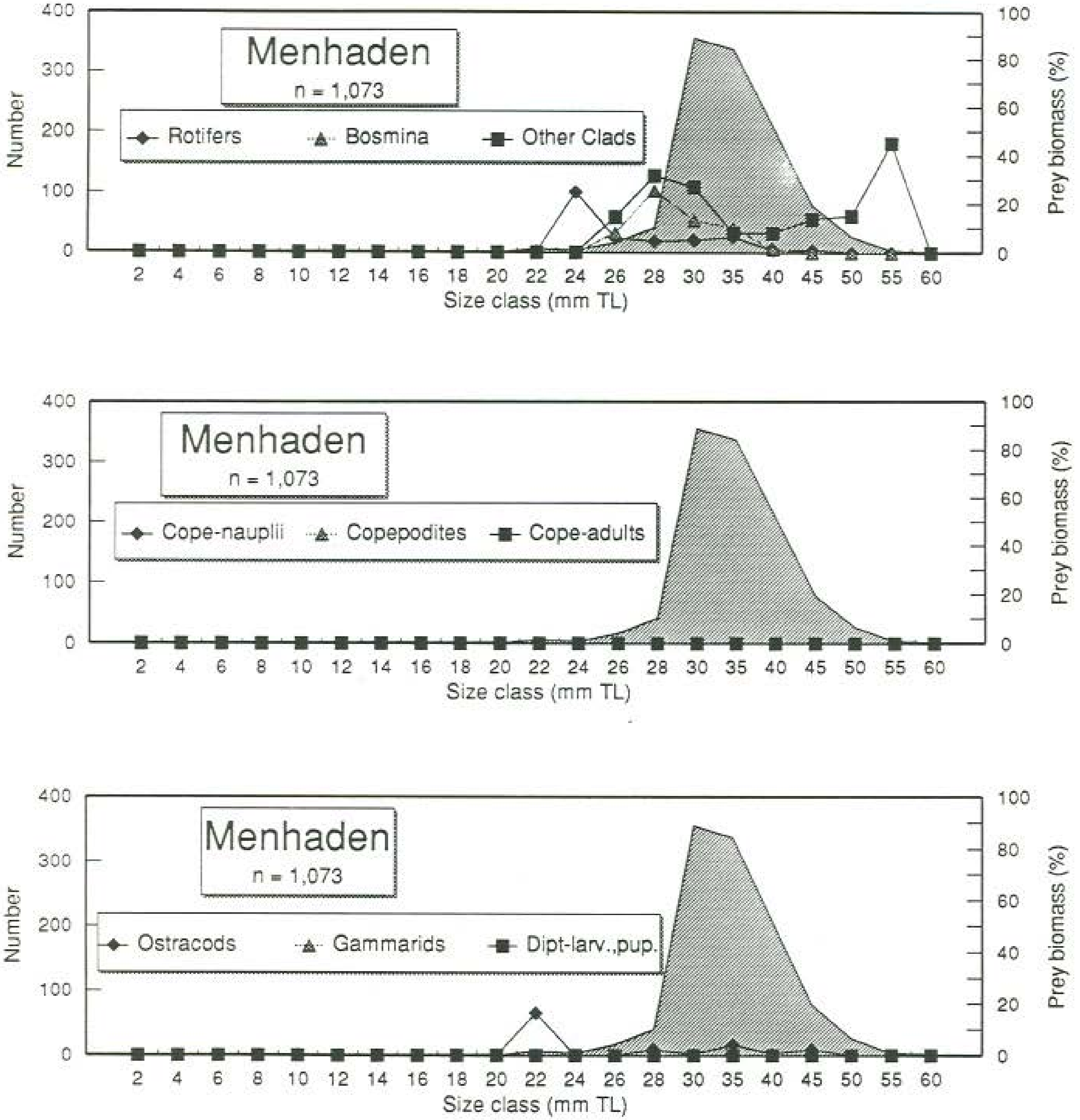

Figure 16. The number of young Atlantic menhaden examined by size class (shaded area), and the average relative biomass (%) of prey in fish stomachs within a size class.

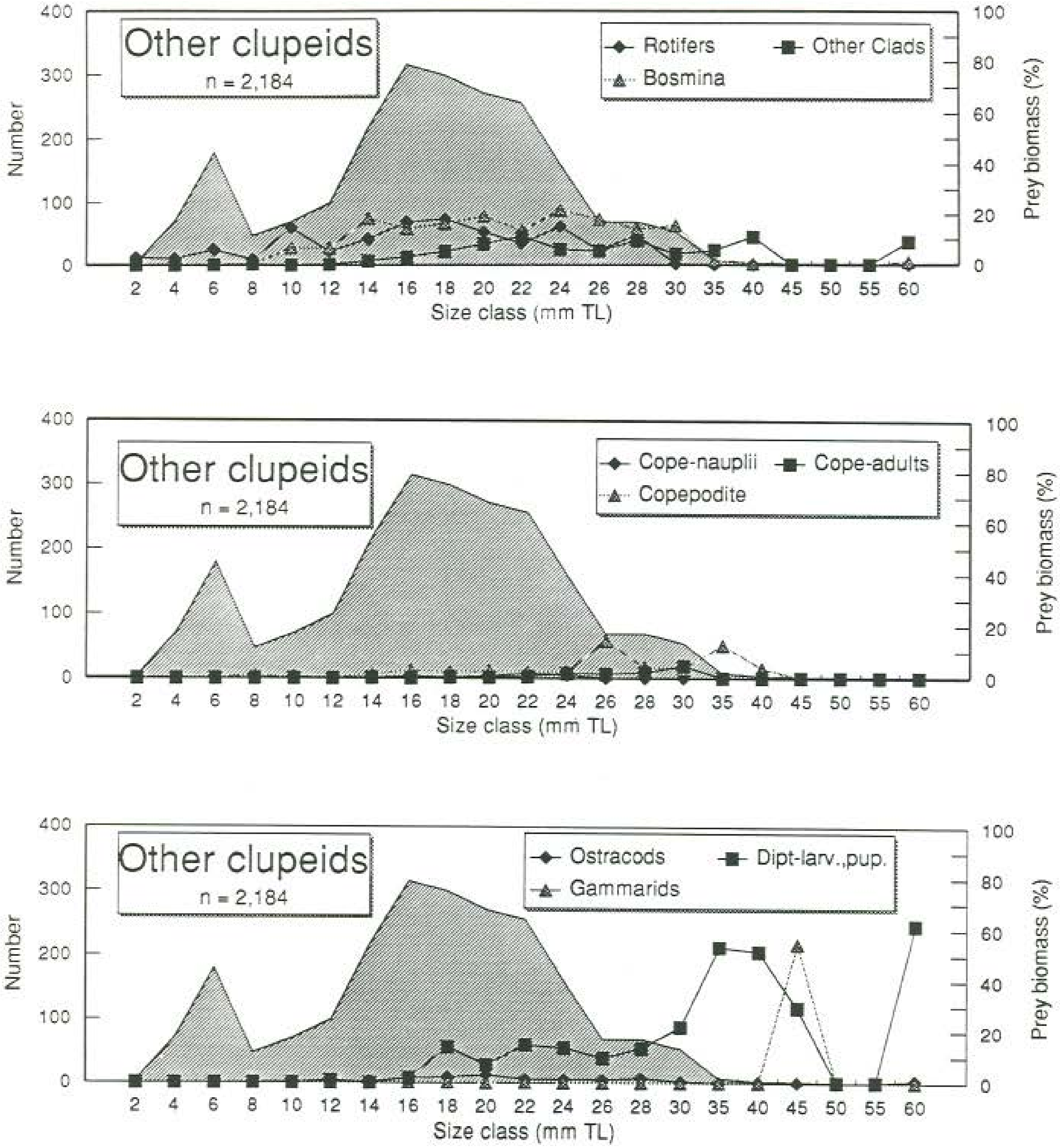

Figure 17. The number of young Clupeids (excluding menhaden) examined by size class (shaded area), and the average relative biomass (%) of prey in fish stomachs within a size class.

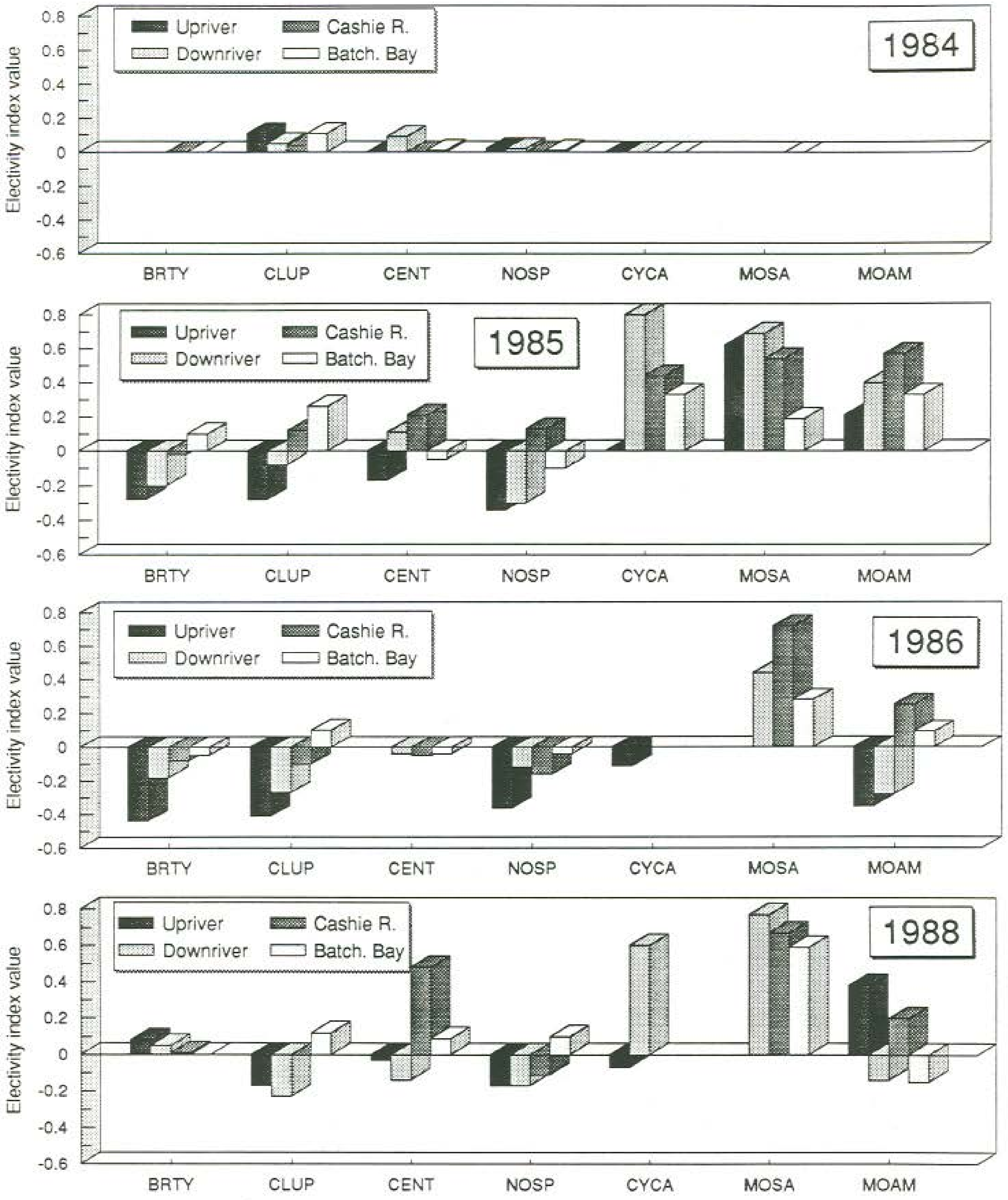

Figure 18. Comparison of Strauss Electivity Index values, for prey item *Bosmina*, for seven species of finfish at four locations within the lower Roanoke watershed.

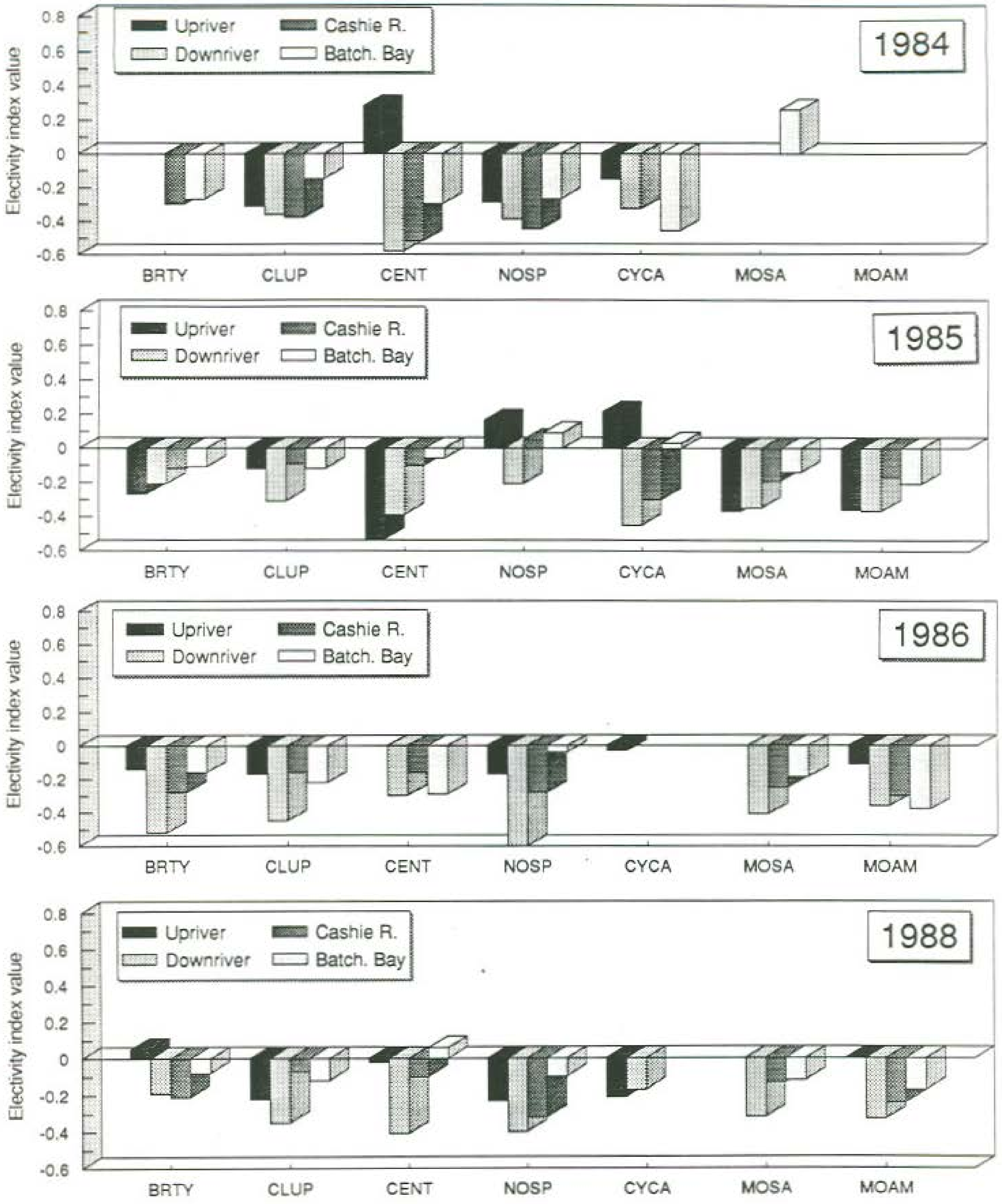

Figure 19. Comparison of Strauss Electivity Index values, for prey item cladocerans (excluding *Bosmina*), for seven species of finfish at four locations within the lower Roanoke watershed.

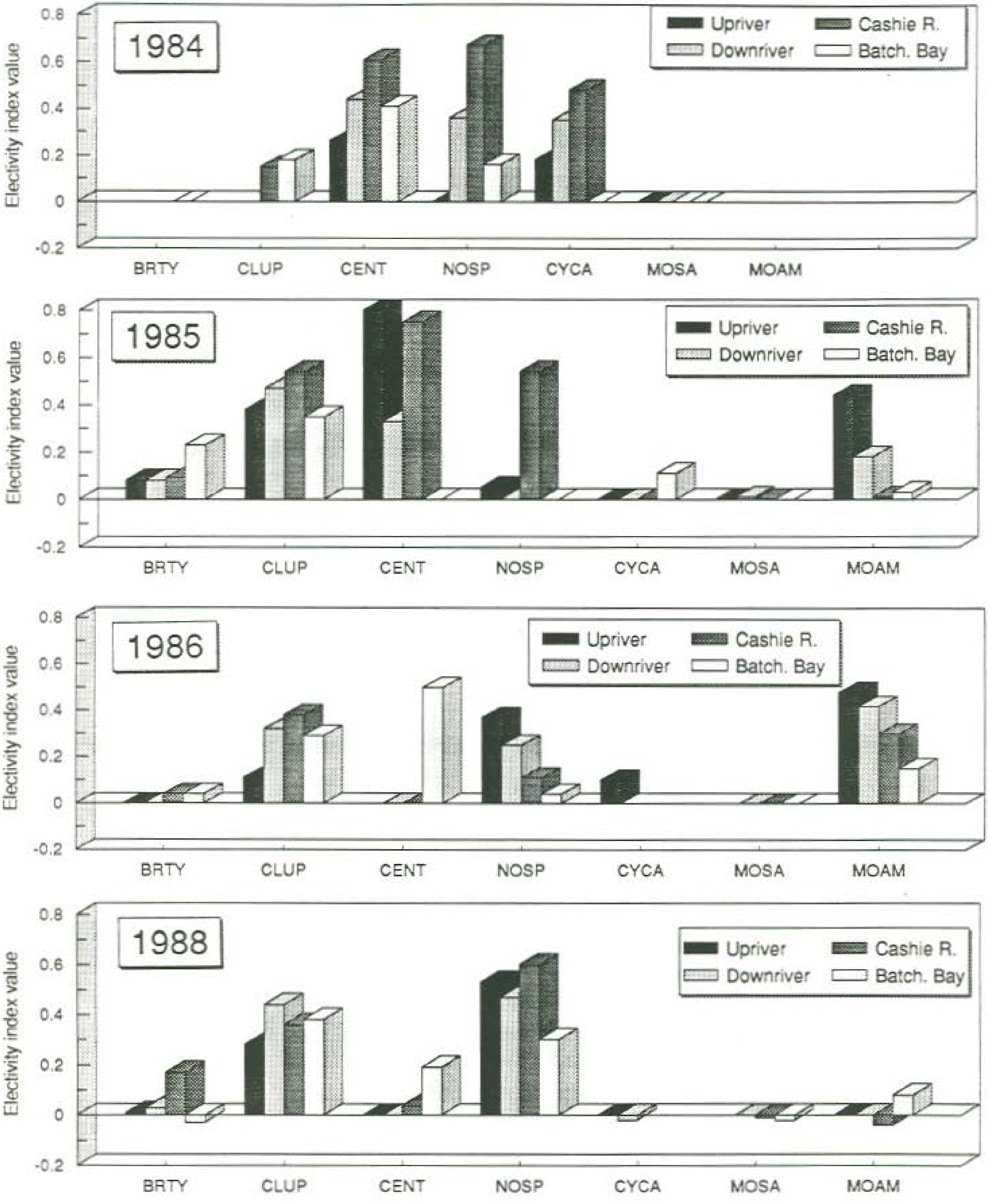

Figure 20. Comparison of Strauss Electivity Index values, for prey item rotifers, for seven species of finfish at four locations within the lower Roanoke watershed.

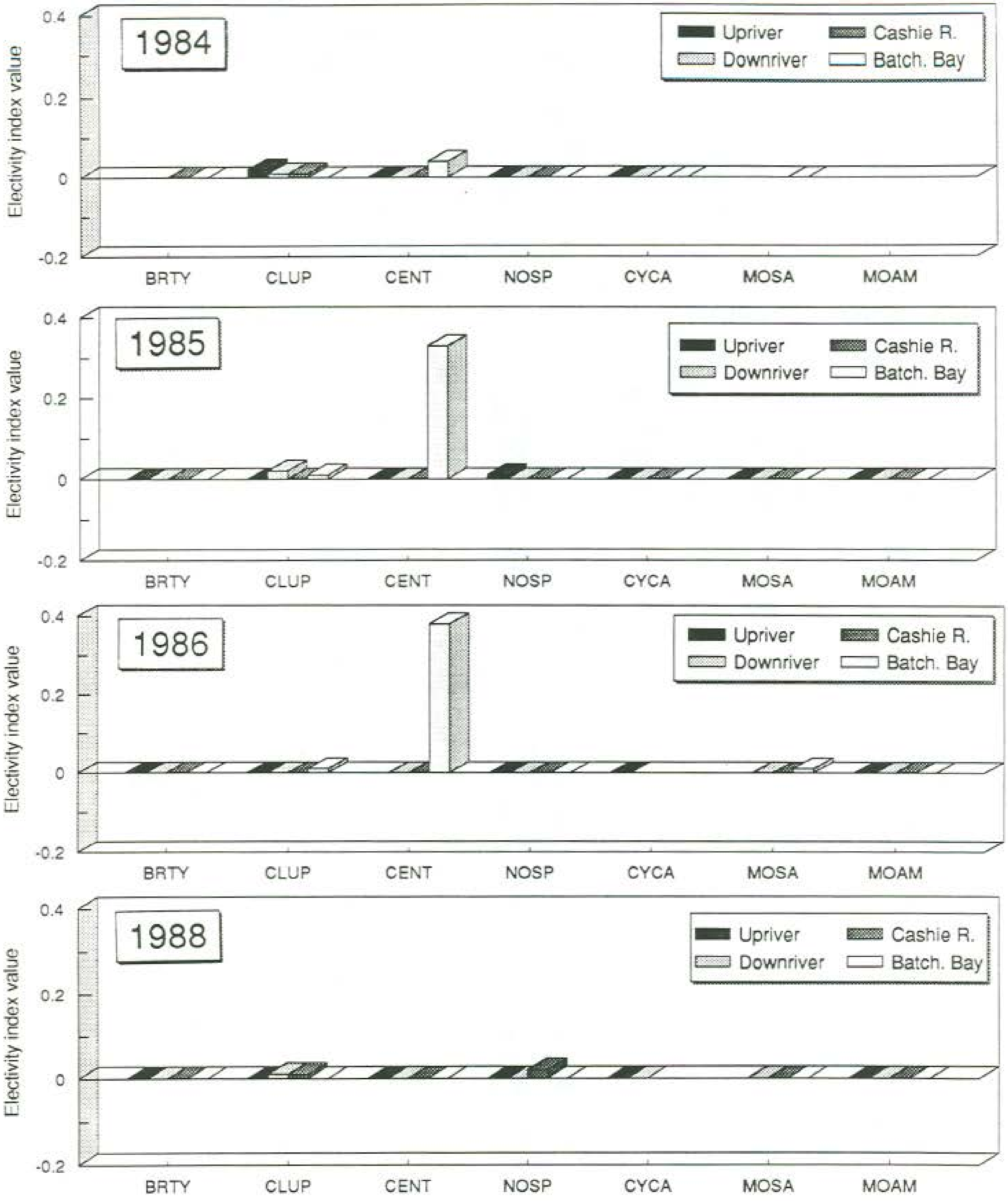

Figure 21. Comparison of Strauss Electivity Index values, for prey item copepod nauplii, for seven species of finfish at four locations within the lower Roanoke watershed.

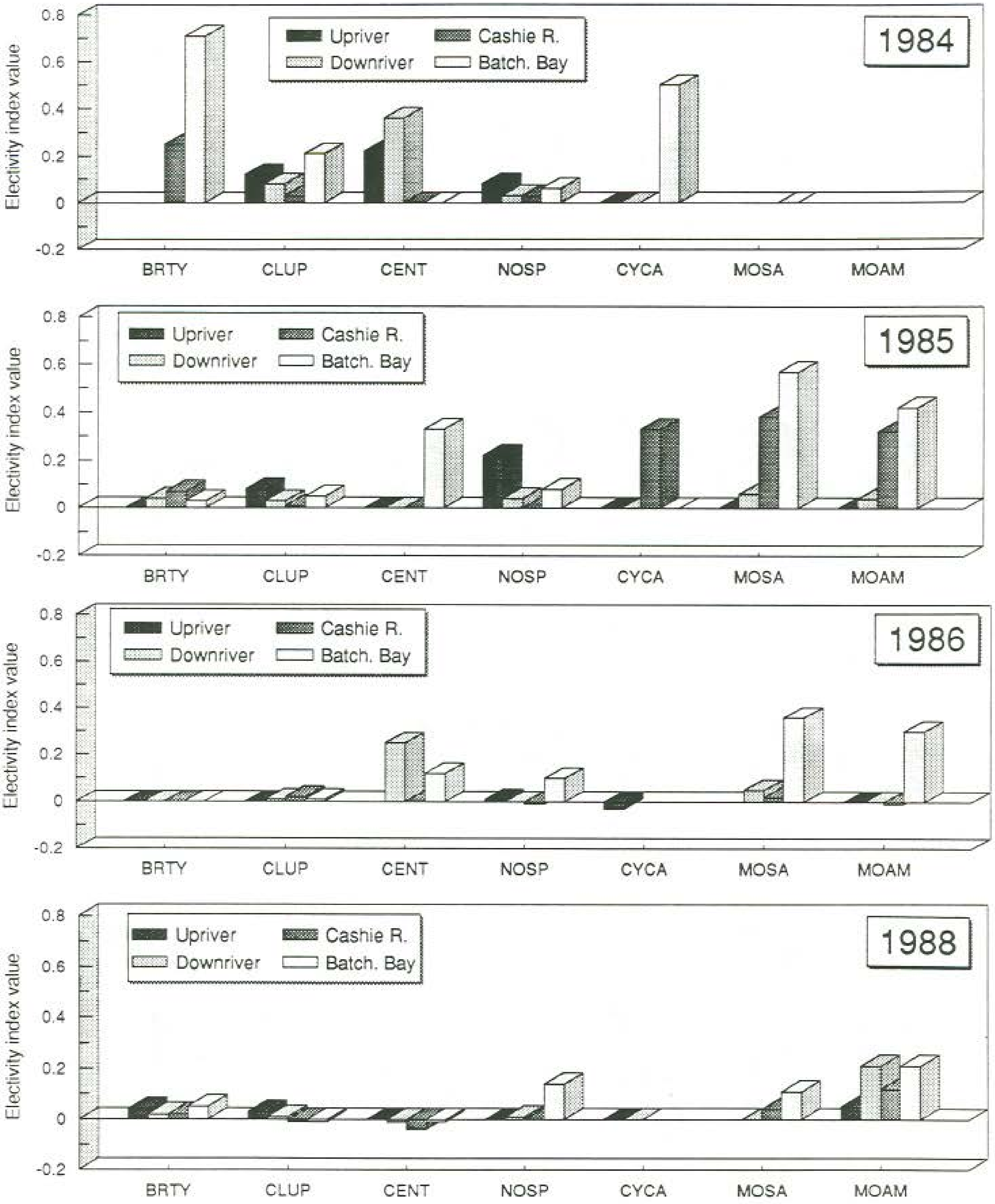

Figure 22. Comparison of Strauss Electivity Index values, for prey item copepodid copepods, for seven species of finfish at four locations within the lower Roanoke watershed.

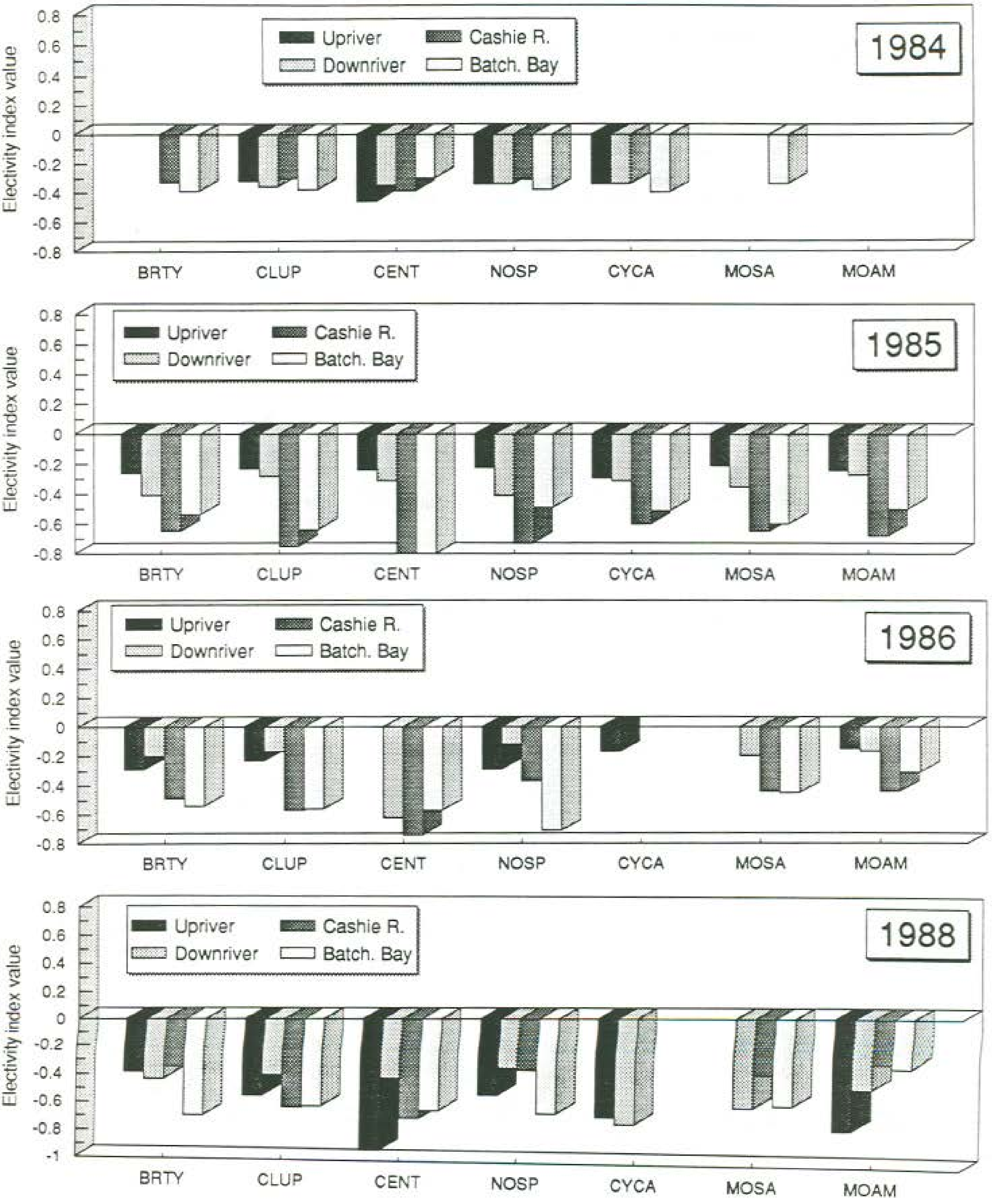

Figure 23. Comparison of Strauss Electivity Index values, for prey item copepod adults, for seven species of finfish at four locations within the lower Roanoke watershed.

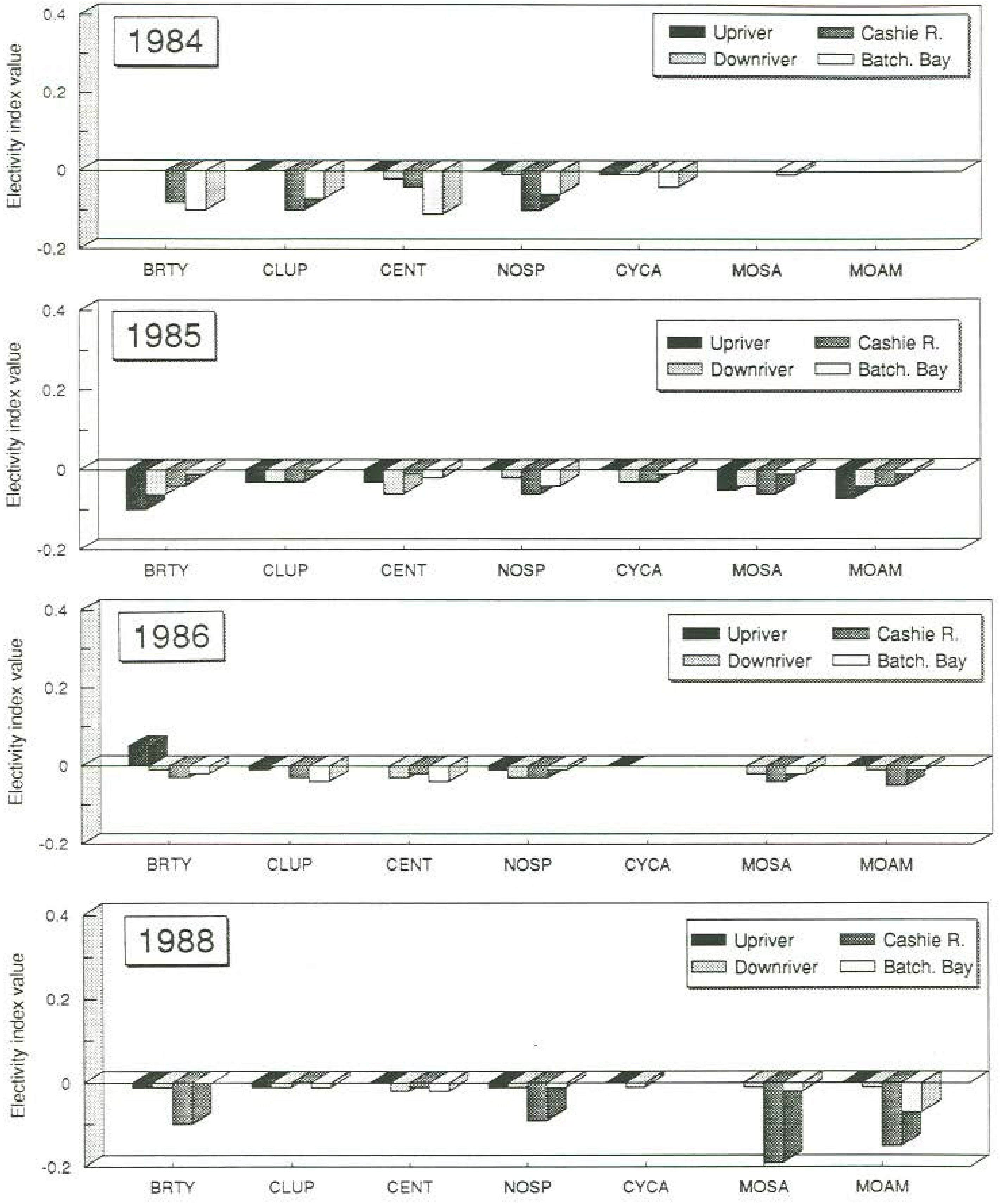

Figure 24. Comparison of Strauss Electivity Index values, for prey item ostracods, for seven species of finfish at four locations within the lower Roanoke watershed.

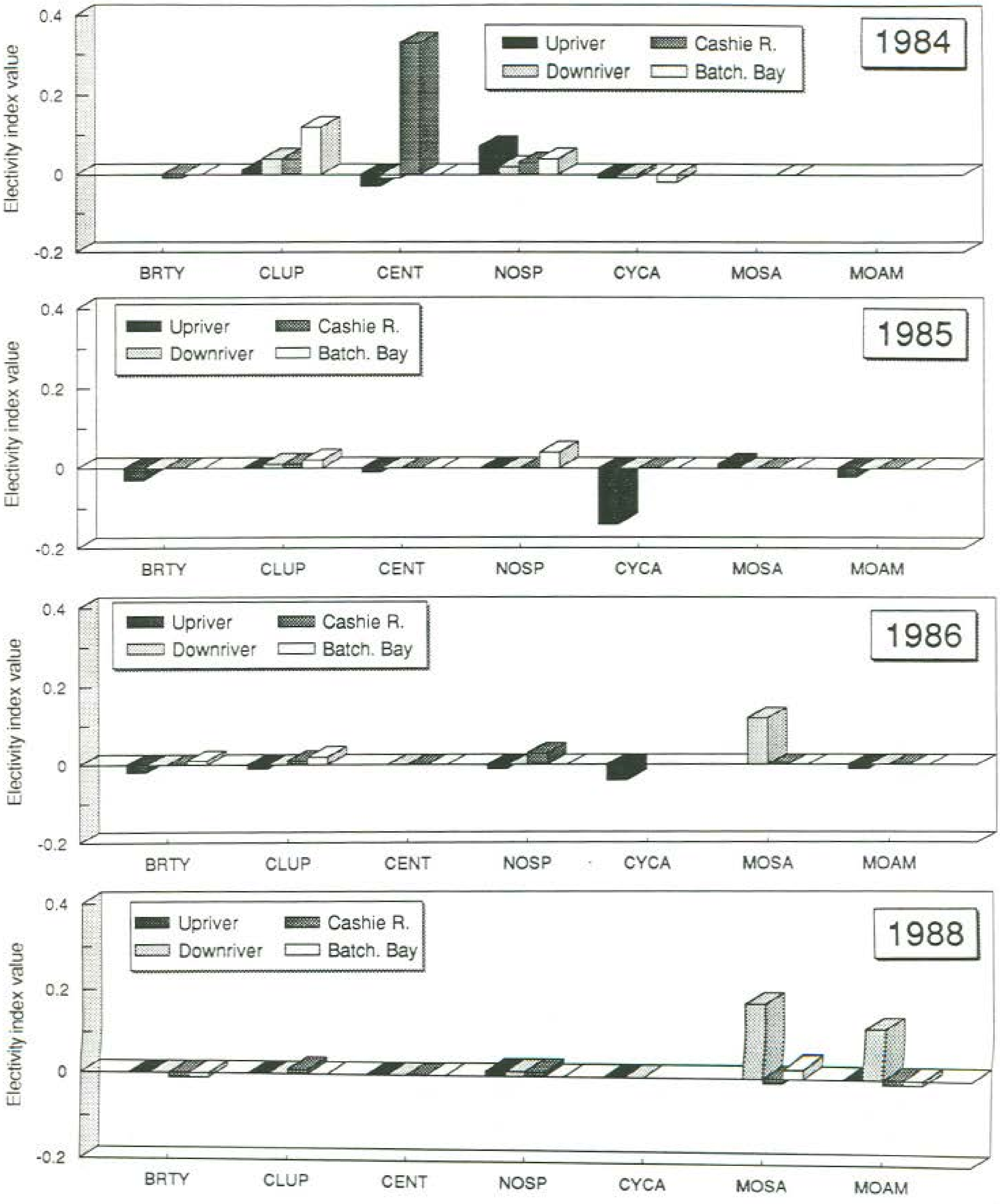

Figure 25. Comparison of Strauss Electivity Index values, for prey item Diptera larvae and pupae, for seven species of finfish at four locations within the lower Roanoke watershed.

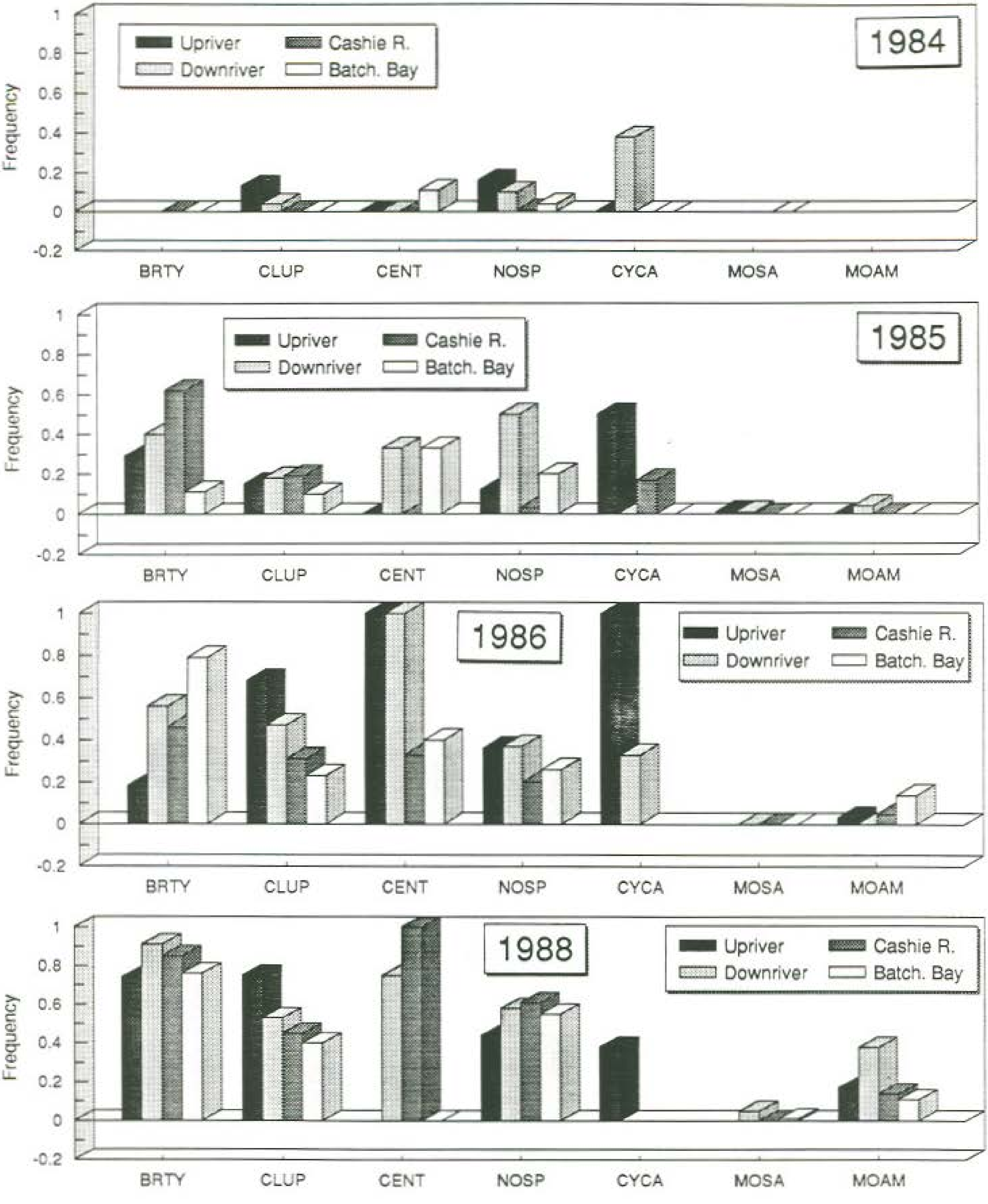

Figure 26. Comparison of algae frequency of occurrence in stomachs of seven species of finfish at four locations within the lower Roanoke watershed.