LARVAL STRIPED BASS AND THE FOOD CHAIN: CAUSE FOR CONCERN?

Roger A. Rulifson, John E. Cooper, Donald W. Stanley[1]

ABSTRACT: In 1984 and 1985, phytoplankton, zooplankton, and striped bass (Morone saxatilis) larvae were collected from the lower Roanoke River, delta, and western Albemarle Sound, North Carolina, to determine whether a disruption of the food chain might be responsible for a dramatic decline in the Albemarle striped bass stock. Zooplankton density was lower than might be expected based on the phytoplankton to zooplankton ratio. Apparently zooplankton abundance was limited by some factor other than phytoplankton. Peak zooplankton abundance occurred in the Roanoke delta, probably held in the area by the mixing of Roanoke waters with western Albemarle Sound. Larval striped bass had relatively poor feeding success as exhibited by few zooplankton prey items in larval fish stomachs. In 1984, larval striped bass were transported downstream too rapidly by high freshwater discharge and passed through the delta into the western Sound before first feeding was initiated. Reduced flow conditions in 1985 resulted in the zooplankton developing earlier in the season and larger than that observed in 1984. However, striped bass larvae were transported downstream too slowly. First feeding was initiated upstream of the peak zooplankton community. Flow of the Roanoke River watershed below the fall line is controlled primarily by the Roanoke Rapids dam located at River Mile 137. We conclude that river flow controls the development of the zooplankton community and timing of striped bass larvae transported from the historical spawning grounds upstream.
(KEY TERMS: Striped bass, zooplankton, phytoplankton, Roanoke River, Albemarle Sound, food chain.)

INTRODUCTION

Striped bass (Morone saxatilis) is an important national resource in the USA and one of the most important commercial and recreational species along the Atlantic seaboard. Adults of the coastal stocks north of North Carolina ascend natal rivers in the spring to spawn in fresh or brackish waters and remain for a short period before returning to the ocean. Ocean migratory patterns of these stocks were summarized by Hardy (1978), Setzler et al. (1980), Boreman and Lewis (1987), Rulifson et al. (1987), and others. Striped bass populations in North Carolina and throughout the southeastern USA are primarily endemic and riverine (McIlwain, 1980).

Production and harvest of striped bass have been in decline since the mid-1970s throughout its range (Rulifson et al., 1982a, 1982b, 1987; USDOI and USDOC, 1985). Overharvest was suspected as one contributor to the decline of these stocks. Several actions by the U.S. Congress and the Atlantic States Marine Fisheries Commission have reduced harvest until stocks recover and studies to identify additional causes for decline are completed (Chafee, 1980; ASMFC, 1981; USDOI and USDOC, 1985).

[1]Respectively: Associate Scientist, Fisheries Biologist, and Senior Scientist, Institute for Coastal and Marine Resources, East Carolina University, Greenville, NC 27858

In North Carolina, the largest striped bass population is in Albemarle Sound. The major spawning area for this stock is located in the Roanoke River (Figure 1, a swiftly-flowing narrow river that empties into the extreme western end of Albemarle Sound. Spawning occurs upstream between the towns of Halifax (River Mile 120) and Weldon (RM 130), North Carolina, from late April through early June (Hassler et al., 1981). The historical spawning grounds farther upstream were blocked by construction of the Roanoke Rapids Dam at RM 137 (McCoy, 1959). Eggs develop to the hatching stage as they are transported downstream by currents. After hatching, the larvae are transported to the Roanoke River delta and eventually reach the historical nursery grounds of western Albemarle Sound. This stock has been in decline for over a decade; a strong year class of Roanoke striped bass has not been observed since 1970, and no significant year classes have been produced since 1976 (Hassler et al., 1981; USDOI and USDOC, 1985).

Several factors may contribute to the decline of the Roanoke population. Reduced egg viability was suspected as the initial cause for decline of the adult population (Guier et al., 1980; Hassler et al., 1981), although "adequate" numbers of viable striped bass eggs are spawned each year to produce sufficient recruitment to the population (Kornegay, 1981; Kornegay and Mullis, 1984). Another potential problem may be poor survival of juvenile striped bass on the nursery grounds of the western Sound. The juvenile trawl index conducted each year suggests that the numbers of juvenile striped bass are too low to produce sufficient recruitment to the population (Hassler et al. 1981). Low recruitment of larvae and early juveniles to the nursery ground was observed in 1983 (Rulifson 1984a). Predation of larvae by finfish predators is not considered to be a major contributor to mortality of striped bass larvae at this time because of the low numbers of larvae available relative to larval abundance of other fish species (Rulifson 1984b). These studies suggest that excessive mortality occurs between hatching and juvenile life stages.

The availability of zooplankton prey for larval striped bass was suspected after studies conducted in 1982 and 1983 indicated low abundance of zooplankton in Albemarle Sound and little or no prey items in larval fish stomachs (Rulifson 1984a). Zooplankton densities were several orders of magnitude lower than for other systems supporting striped bass populations (e.g., Potomac River Estuary; Sacramento-San Joaquin Estuary). The study described herein was initiated in 1984 to meet the following objectives: 1) to determine the relative abundance of striped bass post-hatch life stages in the lower Roanoke River, delta, and western Sound; 2) to determine the location in the river at which post-yolksac feeding is initiated relative to river flow; 3) to determine the availability of zooplankton prey in the river, delta, and western Sound; 4) to determine the density and species composition of phytoplankton algae available to support zooplankton production; and 5) to determine prey items selected by young striped bass. Field work is scheduled through the 1989 spring spawning period. Results of the 1984 and 1985 efforts were presented by Rulifson et al. (1986); portions of that study were summarized and used in this manuscript.

STUDY SITE DESCRIPTION

The Roanoke River watershed comprises the largest basin of the North Carolina estuaries (Giese et al. 1979). The widest portion of the river (480 m) occurs near its mouth; areas upstream of Plymouth may be less than 16 m wide. The delta is a drowned river valley filled with sediments, forming a system of distributaries emptying into western Albemarle Sound (Figure 1). Water depth usually varies between 2.5 m and 5.5 m but can change rapidly over a short distance. Within the delta, shallow mudbanks may extend several meters from shore to terminate in dropoffs over 24 m deep. A navigation channel is maintained in the Roanoke mainstem from Albemarle Sound to Palmyra, North Carolina.

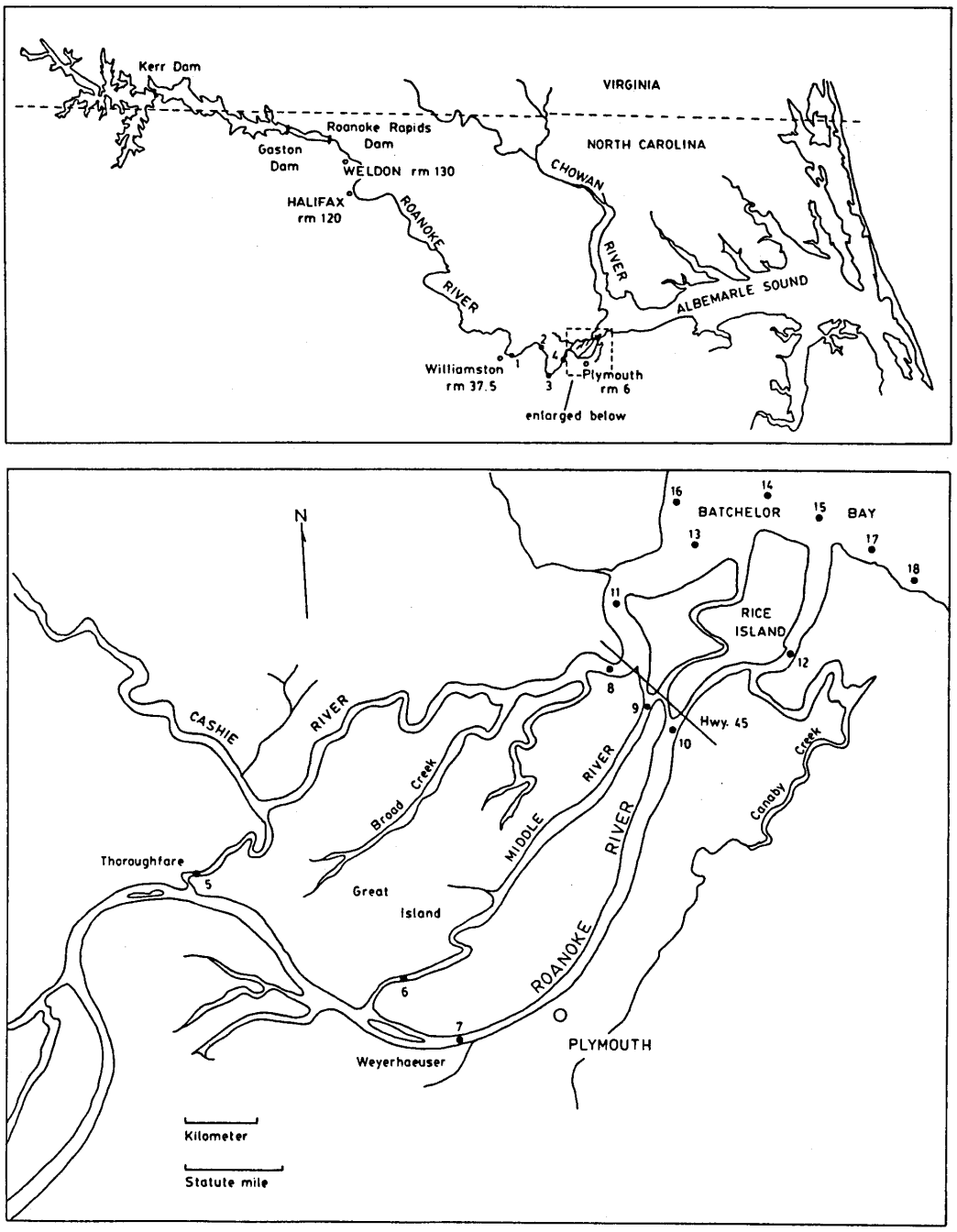

Figure 1. The Roanoke River watershed below the John H. Kerr Reservoir showing the striped bass spawning grounds between Weldon and Halifax and the locations sampled for phytoplankton, zooplankton, and larvae in 1984 and 1985.

Flow of the Roanoke River is highly regulated by a number of reservoirs upstream: in Virginia; Smith Mountain Lake, Philpott Lake, Leesville Lake, John H. Kerr Reservoir; and Lake Gaston and Roanoke Rapids Lake in North Carolina. Of these, the Roanoke Rapids reservoir is most important to the lower river and Sound; 87% of the flow to the coastal watershed is provided by its discharge. Regulation of flow by the reservoir system virtually precludes intrusion of saltwater into the lower Roanoke River except in cases of severe drought (Giese et al. 1979).

METHODS

Sample Collection

Phytoplankton, zooplankton, and ichthyoplankton samples were collected in the spring of 1984 and 1985 just prior to the estimated peak spawning activity for striped bass and continued into June when striped bass larvae were no longer present in samples. Field trips were conducted from 18 May to 18 June in 1984, and 26 April to 10 June in 1985. Similar sampling locations were used in both years. Stations 1-4 in the lower river (Figure 1) were sampled on alternate nights for a two-week period. Eleven stations in the delta and Sound near the town of Plymouth were sampled on alternate nights beginning at dusk, requiring four to six hours to complete the trip. In 1984 many larvae were swept downstream and into Batchelor Bay (western Albemarle Sound) due to high freshwater runoff; therefore, Stations 16-18 were added late in the spawning season and Stations 5-7 were dropped to concentrate effort over a greater area of the western Sound. Total effort for 1984 was 14 sampling trips and 18 stations. In 1985, larvae remained in the lower river and delta; all river stations were sampled for the entire period and Station 16 in Batchelor Bay was sampled on the last trip (10 June). Total effort for 1985 was 20 sampling trips and 16 stations.

Surface phytoplankton samples (whole water) taken from each station were preserved with Lugol's acetic acid-iodine solution (Wetzel and Likens 1979).

In both years, zooplankton samples were collected using nets constructed of 250 um nitex mesh, with a 0.5-m diameter mouth opening and a 1:6 mouth-to-tail ratio. A flowmeter with slow speed propeller (General Oceanics model 2030) was mounted in the net frame to estimate the volume of water filtered. Initially, samples of six-minute duration were taken against the current, but sample time was reduced to three minutes to minimize clogging problems caused by the high concentration of suspended solids in the water. Zooplankton were preserved in 5% buffered formalin containing Rose Bengal.

In 1984, ichthyoplankton samples were collected by towing a Tucker trawl in an oblique manner against the current for six minutes. Each Tucker trawl was constructed of 505 um nitex mesh material with a 0.5-m^2 mouth opening and 1:6 mouth to tail ratio. A flowmeter with high-speed propeller was mounted in the mouth of each net. Stations 1-4 were sampled by towing with a single net, emptying the cup, and then towing a second time. Replicate samples at Stations 6-18 were obtained simultaneously by paired Tucker trawls mounted on the same frame. Station 5 was sampled using the single net from 22 May to 2 June, and by paired nets thereafter. Ichthyoplankton samples were placed on ice for 10 minutes to minimize regurgitation of stomach contents by the larvae, then preserved with 5% buffered formalin containing Rose Bengal.

In 1985, Stations 1-4 were sampled for ichthyoplankton by the same method used in 1984. Stations 6-15 were sampled by towing paired 0.5-m diameter conical nets in an oblique manner for six minutes. Each conical net was constructed of 505 um nitex mesh material with a 1:6 mouth to tail ratio mounted in a bongo frame. Station 5 was sampled by single Tucker trawl for May 4-16, and by paired conical nets thereafter. Samples were preserved by the method used in 1984.

Sample Processing

Larvae and small fish were removed from all ichthyoplankton and zooplankton samples for enumeration and identification. Morone larvae were identified and measured, and stage of development was noted using methods described by Mansueti (1964) and Lippson and Moran (1974). Those Morone larvae in feeding condition were examined for gut contents. Each food item was identified to the lowest taxon practical and enumerated. The average number of each food item ingested per fish was calculated by counting the total number of each food item and then dividing by the number of fish examined that contained food.

Zooplankton samples were processed 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 to the lowest practical taxon and enumerated. This procedure was repeated two more times. The average number of of each taxonomic group was calculated and reported as number per 100m3 of water filtered. Zooplankton wet weight biomass (ug/l) was estimated by measuring lengths of representative animals from the samples and using dry weight/length relationships described by Dumont et al. (1975).

Phytoplankton cell densities were determined using the membrane filtration method (A.P.H.A. 1975). The preserved algae were concentrated by filtering the sample through a 0.45-um pore size membrane filter. Concentrated algae were counted using an inverted microscope and reported as numbers 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.

RESULTS

Detailed discussion of the results for each food chain component and its relationship to larval striped bass was presented by Rulifson and Stanley (1985) and Rulifson et al. (1986). Results described below is a general summary of the trends found in the two-year period.

Striped Bass Eggs

High freshwater runoff in 1984 (Figure 2) resulted in the appearance of striped bass eggs downstream as far as the Roanoke River mouth (Station 12). Of the eggs collected, greatest abundance (28%) was at Station 2 between Williamston and Jamesville (Figure 1). An additional 24% were collected at Williamston (Station 1) and 21% at Jamesville (Station 3). Two percent of the eggs were in the Roanoke mainstem at Weyerhaeuser (Station 7), and 7% were collected from the river mouth (Station 12). No eggs were collected from either the Cashie River or Middle River, the two distributaries of the river delta. Julian date and river flow explained 60% of the variability in average egg abundance ($n=11$; $df=9$; R^2 0.60; $p=0.025$) in the study area for 1984 using multiple linear regression techniques (SAS Institute, Inc. 1985). Pearson product-moment correlation analyses revealed that egg abundance was inversely correlated with sampling date ($r= -0.702$) and discharge from the dam (as measured by the USGS gage below the Roanoke Rapids Dam) lagged by three days ($r= -0.685$).

Low flow conditions prevailed in 1985 (Figure 2). No striped bass eggs were collected within the study area in this year.

Striped Bass Larvae

In 1984, 2,829 larvae were collected in the study area. Stage 1 larvae (i.e., those larvae possessing yolk and oil) comprised 96% of the total; Stage 2 larvae (oil

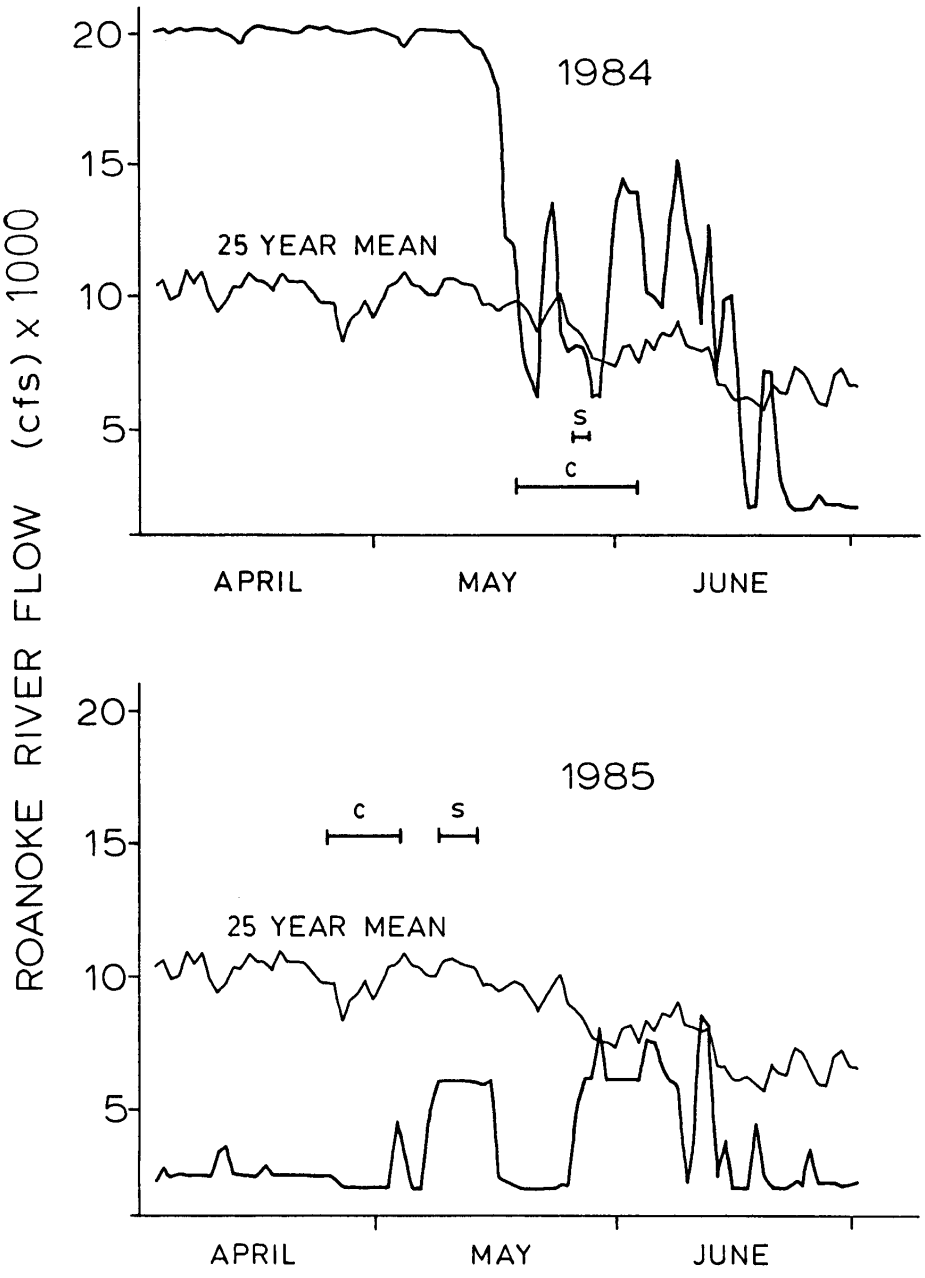

Figure 2. Flow of the Roanoke River below Roanoke Rapids Reservoir, recorded in cubic feet per second (cfs) by the USGS gage near Weldon, in 1984 and 1985. A minimum 6,000 cfs discharge is required under current guidelines during striped bass spawning activity (shown as a plateau in May 1985). C = peak abundance of Cladocera; S = peak abundance of larval striped bass.

only) made up the remainder. Larvae were captured from Williamston (Station 1) into Batchelor Bay (Stations 13, 14, and 15). Most were collected between Williamston and Jamesville (39%) and the Roanoke River mainstem (35%) from Stations 7, 10, 12, and 15. An additional 16% were found in Middle River (Stations 6 and 9) and 10% in the Cashie River (Stations 5, 8, 11, 13, and 14).

Of those larvae collected in 1984, only 1% (30 fish) were in feeding condition, and just 11% of those contained food items in stomachs. Greatest feeding occurred in Batchelor Bay (Stations 14 and 15) during the period 29 May to 8 June 1984. Prey items were Daphnia and beetle larvae.

In 1985, 3,217 striped bass larvae were collected, the majority of which (67%) were Stage 1 larvae. Areas of distribution ranged from Williamston downstream into Batchelor Bay. The greatest number of larvae (46%) was collected from Middle River (Stations 6 and 9). A large portion was present in the Roanoke mainstem between Williamston and Jamesville (22%) and from Plymouth to the Roanoke mouth (18%; Stations 7, 10, 12, and 15). An additional 18% was recovered from the Cashie River (Stations 5, 8, 11, 13 and 14).

The number of larvae with food items in 1985 increased substantially over those examined in 1984. Forty-eight percent of the Stage 1 larvae contained prey (in order of abundance): Bosmina, copepodite copepods, ostracods, rotifers, unidentified insects, midge larvae, copepod eggs, and detritus. In 1985, Stage 2 larvae ranged in size from 15.0 to 23.5 mm total length (TL). Only 39% of the Stage 2 larvae contained food, and the prey items were larger than those consumed by Stage 1 larvae: copepodite and adult copepods, Daphnia, chironomids, amphipods, clams, and fish larvae.

Zooplankton

Zooplankton densities were quite low in 1984, probably caused by high freshwater discharge from the watershed upstream. Highest average densities were at Station 9 (Middle River), Station 11 (Cashie River), and Station 16 (Batchelor Bay), with mean values of 1123, 935, and 906 organisms/100 m^3. No correlations were observed between mean zooplankton density and sampling date or river flow, and multiple regression analyses did not pick a significant statistical model to predict zooplankton abundance. Cladocerans comprised the most abundant zooplankter group in 1984; their relative contribution (except Leptodora) averaged 51.0% by station and 53.2% by date. Copepods were the second most abundant group, comprising 31.5% of the catch by station and 31.3% by date. Cyclopoids were the most abundant of the copepod groups in 1984.

Zooplankton densities were higher in 1985, probably as a result of reduced flow conditions within the river. Highest average densities occurred at Station 8 (4,087/100 m^3) and Station 11 (2,262/100 m^3). Batchelor Bay Stations 13 and 15 also had high average zooplankton concentrations (1,926 and 1,951/100 m^3, respectively). Zooplankton densities were significantly correlated ($p<0.05$) with Julian date ($r= -0.725$), river flow ($r= -0.493$), and phytoplankton cell densities ($r=0.522$). The variable Julian date explained approximately 51% of the variability in zooplankton concentrations in 1985 using the Stepwise (maximum r-square improvement) Procedure (SAS Institute, Inc., 1985). Copepods were the most abundant zooplankter group in 1985; cyclopoid copepods were dominant. Relative contribution of copepods to zooplankton catches was 62.1% by date and 43.2% by station, a considerable increase in abundance over that observed in 1984. Cladocerans were the second most abundant group in 1985, representing a relative contribution of 29.2% by date and 43.8% by station. Bosmina was the most abundant cladoceran group, comprising 12.4% of all zooplankton by date and 19.1% by station. Daphnia was the second most abundant, representing 7.6% of all zooplankton by date and 13.1% by station. Cladocerans were patchy in distribution. Stepwise regression selected the variable Julian date and average water temperature as

best predictors of Bosmina abundance (R^2=0.595; n=20; P<0.001). For Cladocera as a group, only the sampling date (Julian date) was an important predictor of average cladoceran abundance (R^2=0.468; n=20; P<0.001).

Phytoplankton

Since the lower Roanoke River is tidal freshwater, it is not surprising that the phytoplankton species composition there more closely resembles that in a lake than that from most estuarine environments. Green algae and diatoms made up about 40% and 35%, respectively, of the average total wet weight biomass in 1984-1985; diatoms, chrysophytes, and dinoflagellates contributed about equally to the remaining 25% of total biomass. Most of the algae are small species that should be usable as food for grazing zooplankton in the river. There were no algae found in significant quantities that have been reported to be toxic or otherwise undesirable to zooplankters (e.g., blue-green algae).

DISCUSSION

A comparison of zooplankton and phytoplankton biomass in the Roanoke suggests that phytoplankton abundance is more than adequate to support the zooplankton. Figure 3 is a plot of log phytoplankton biomass vs. log zooplankton biomass for all the Roanoke samples collected in 1984 and 1985. It also shows similar data compiled by McCauley and Kalff (1981) from 13 lakes. There is a great deal of variability in the data, both for the Roanoke and for the lakes, but the point of the plot is that there does seem to be a significant difference between the Roanoke results and those for the lakes. Namely, most of the Roanoke phytoplankton biomass values fall within the lake range, while the Roanoke zooplankton biomasses are much lower than those for the lakes. Thus, the Roanoke zooplankton: phytoplankton biomass ratios (0.01-0.001:1) are much lower than those for the surveyed lakes (mean about 1.0). Our conclusion is that this is evidence that even though zooplankton production in the lower Roanoke River is very low, is not limited by phytoplankton production.

Based on examination of stomach contents and zooplankton samples, we conclude that river flow may be a major factor in controlling zooplankton abundance and positioning of the larvae to the food source. Figure 4 is a composite drawing of all samples for all dates to indicate the relative abundance of the food source and striped bass larvae. Since larvae consume only selected zooplankton groups, we have chosen cladoceran abundance to depict prey availability. In 1984, greatest cladoceran abundance was concentrated within the Roanoke River delta. Stage 1 larvae were present upstream of this area. Both the abundance of striped bass larvae and Cladocera coincided temporally as depicted in Figure 2. Spatially, however, the larvae were swept through the delta and into western Albemarle Sound by high freshwater discharge before they could physically develop to the feeding stage (Figure 4). Thus in 1984, larvae and the food source were mismatched due to high freshwater discharge.

The opposite problem occurred in 1985. Under the reduced flow regime, the cladoceran community had the opportunity to increase in abundance within the delta, probably held in this area by the mixing of downstream waters with Albemarle Sound waters. However, larval striped bass were transported downstream too slowly and feeding was initiated upstream away from peak cladoceran abundance. Again, larvae and the food source were mismatched, but this time temporally (Figure 2) and spatially (Figure 4) due to low flow conditions.

We hypothesize that under medium flow conditions (e.g., 6,000-10,000 cfs), the zooplankton community might develop more quickly by added input of zooplankters from small tributary creeks and floodplains, but will still remain within the Roanoke River delta by the mixing action of Roanoke waters with western Albemarle Sound. Striped

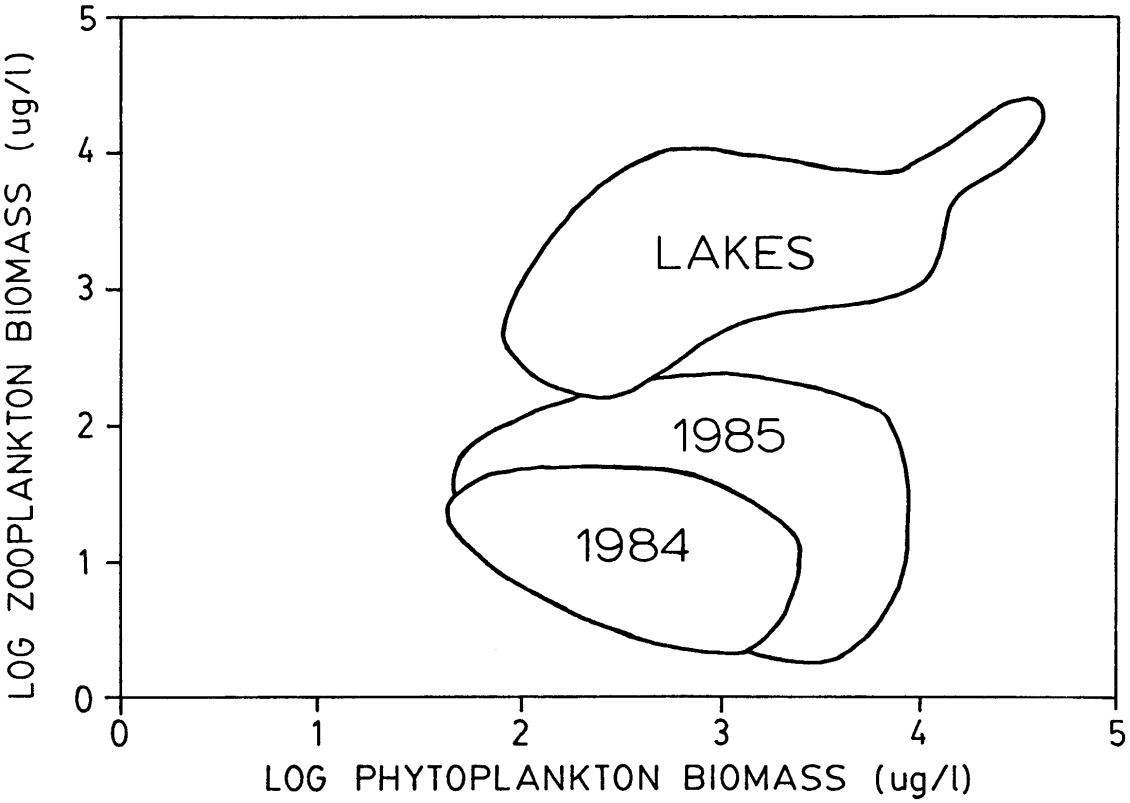

Figure 3. The relationship of zooplankton biomass versus phytoplankton biomass in the lower Roanoke River study area during the springs of 1984 and 1985. Phytoplankton biomass is normal but zooplankton biomass is low compared to the ratios established for 13 lakes by McCauley and Kalff (1981).

bass larvae should then be transported downstream to the zooplankton food source just as first feeding is initiated. Under medium flow conditions, we expect that both the larvae and the food source will be matched temporally and spatially, resulting in a striped bass young-of-year index higher than those observed since the late 1970s.

ACKNOWLEDGMENTS

This research was funded, in part, by the U.S. Department of the Interior, Fish and Wildlife Service, under the Anadromous Fish Conservation Act (PL89-304). A number of people contributed to the success of this project, and to them we owe our gratitude. Tony Mullis, Pete Kornegay, and Mike Humphreys of the North Carolina Wildlife Resources Commission, Division of Boating and Inland Fisheries, collected the samples at Stations 1-5. David Bronson, Debbie Daniel, and Scott Wood of the Institute were instrumental in field sampling, sample processing, and data management. Mr. Wade Brabble of Plymouth, North Carolina, donated the use of his private dock during the field season in both years.

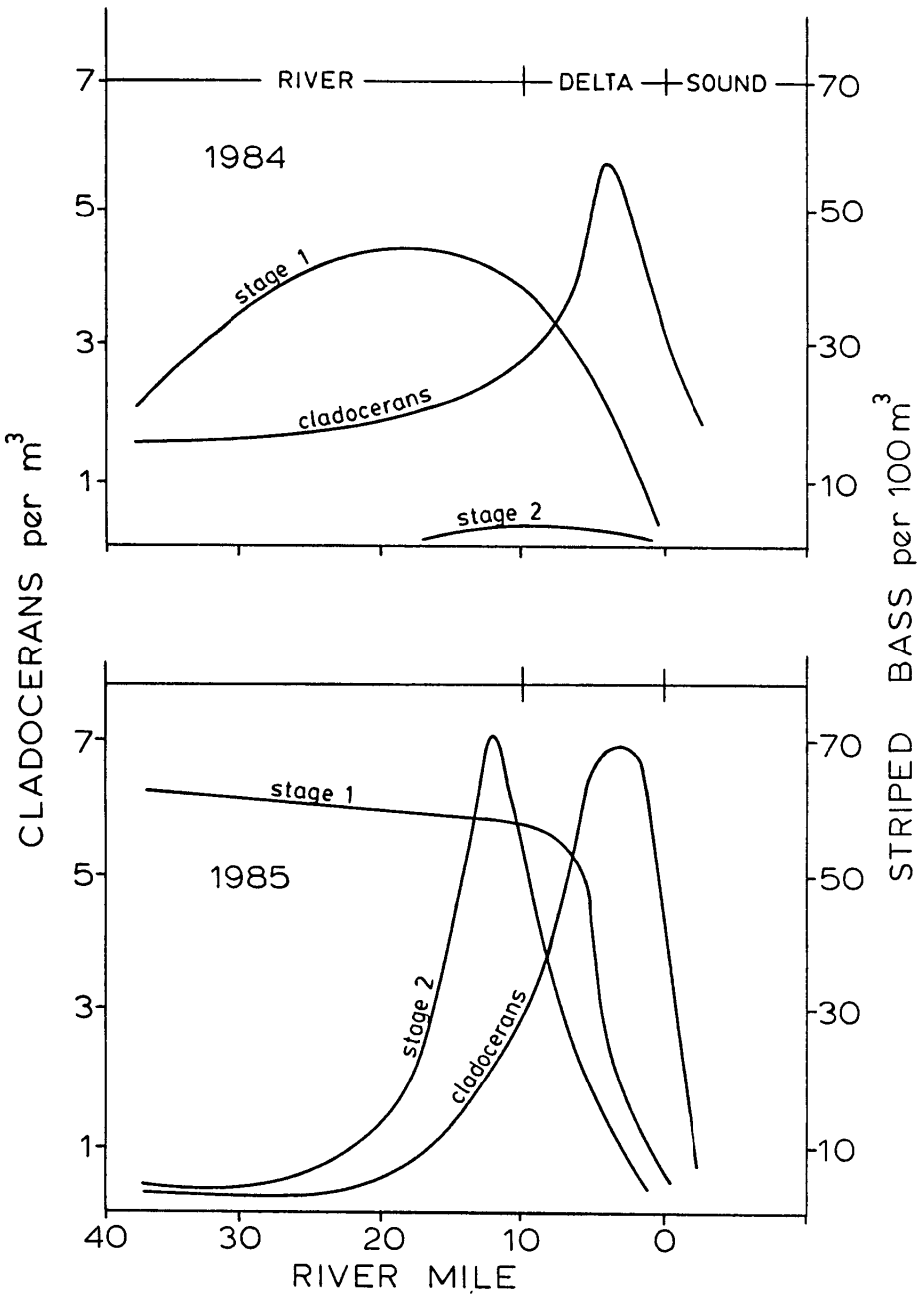

Figure 4. Spatial mismatch of Stage 1 (yolk and oil) and Stage 2 (oil only) striped bass larvae to the food source in the lower Roanoke River under high flow (1984) and low flow (1985) conditions.

LITERATURE CITED

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

ASMFC (Atlantic States Marine Fisheries Commission), 1981. Interstate fisheries management plan for striped bass. Fisheries Management Report 1, Washington, D.C., USA.

Boreman, J., R.R. and Lewis, 1987. Atlantic coast migration of striped bass. American Fisheries Society Symposium 1:331-339.

Chafee, J.H., 1980. The outlook for striped bass recovery, pp. 5-7. in H. Clepper (ed.), Proceedings of the Fifth Annual Marine Recreational Fisheries Symposium. Sport Fishing Institute, Washington, District of Columbia, USA.

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.

Giese, G.L., H.B. Wilder, and G.G. Parker, Jr., 1979. Hydrology of major estuaries and sounds of North Carolina. U.S. Geological Survey, Water Resources Investigations 79-46, 175 p.

Guier, C.R., A.W. Mullis, J.W. Kornegay, S.G. Keefe, H.B. Johnson, and M.W. Street, 1980. Biological assessment of Albemarle Sound-Roanoke River striped bass. Prepared jointly by North Carolina Wildlife Resources Commission and North Carolina Division of Marine Fisheries, 13 p. + Appendices.

Hardy, J.D., Jr., 1978. 1978. Development of fishes of the Mid-Atlantic Bight: An atlas of the egg, larval and juvenile stages. Vol. III. Aphredoderidae through Rachycentridae. U.S. Fish and Wildlife Service, Biol. Serv. Prog. FWS/OBS-78/12, 394 p.

Hassler, W.W., N.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, Special Scientific Report No. 38, 156 p.

Kornegay, J.W., 1981. Investigations into the possible causes of the decline of Albemarle Sound striped bass. Final Report. North Carolina Wildlife Resources Commission, Raleigh, NC, 18 p.

Kornegay, J.W. and A.W. Mullis, 1984. Investigations into the decline in egg viability and juvenile survival of Albemarle Sound striped bass (Morone saxatilis). Final Report on Project F-22, Study VIII. North Carolina Wildlife Resources Commission, Raleigh, NC, 13 p.

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, 282 p.

Mansueti, R.J., 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.

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.

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

McIlwain, T.D., 1980. Striped bass in coastal waters, South Atlantic and Gulf, pp. 37-43. in H. Clepper, ed., Marine recreational fisheries. Vol. 5, Proceedings of the Fifth Annual Marine Recreational Fisheries Symposium. Sport Fishing Institute, Washington, District of Columbia, USA.

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, Completion Report for ECU Contract C-1366, 47 p.

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, Completion Report for Project AFC-18-3, Job 4, 75 p.

Rulifson, R.A., M.T. Huish, and R.W. Thoesen, 1982a. 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, GA, 525 p.

Rulifson, R.A., M.T. Huish, and R.W. Thoesen, 1982b. Status of anadromous fishes in southeastern U.S. estuaries, pp. 413-425. in V.S. Kennedy, ed., Estuarine Comparisons. Academic Press, New York, NY.

Rulifson, R.A., S.A. McKenna, and M.L. Gallagher, 1987. Tagging studies of striped bass and river herring in the upper Bay of Fundy, Nova Scotia. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Completion Report AFC-28.

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, Annual Progress Report for Project AFS-24, Segment 1, 252 p.

Rulifson, R.A., D.W. Stanley, and J.E. Cooper, 1986. 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, Completion Report AFS-24.

SAS Institute, Inc., 1985. SAS User's Guide: Statistics, Version 5 Edition. SAS Institute, Inc., Cary, NC, 584 p.

Setzler, E.M., W.R. Boynton, K.V. Wood, H.H. Zion, L. Lubbers, N.K. Mountford, P. Frere, L. Tucker, and J.A. Mihursky. 1980. Synopsis of biological data on striped bass, Morone saxatilis (Walbaum). NOAA Technical Report NMFS Circular 433, 69 p.

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, District of Columbia, USA.

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