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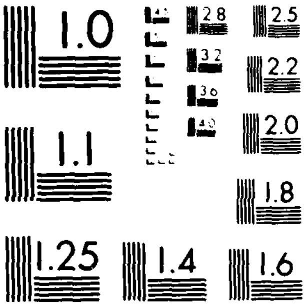

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Zooplankton, when available, may be an important food source for fish fry in lotic habitats. The effects of flood control reservoir operation on the downstream transport of reservoir zooplankton (both microcrustaceans and rotifers) were quantified by examining zooplankton abundances in Barren River Lake, Kentucky, and three downstream stations from August 1980-August 1981. The decrease noted in microcrustacean and rotifer abundance downstream from the dam was attributed to predation, physical destruction, and lack of

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suitable habitat. During stratification (May-September), the abundance of zooplankton was greater in the tailwater than in the reservoir hypolimnion; this difference in abundance suggests that water and associated organisms were being withdrawn from upper levels in the reservoir--as well as from the hypolimnion, where most of Barren River Lake's releases come from and which normally harbors few viable zooplankters. The unstratified reservoir usually contained higher densities of zooplankton than the tailwater.

The results of the study led to the conclusion that implementation of operational procedures to increase discharge of reservoir zooplankton to the tailwater may not be warranted since the complexity of factors determining reservoir zooplankton dynamics precludes their use as a reliable food source for tailwater biota.

PREFACE

This report was prepared by the U. S. Department of the Interior, U. S. Fish and Wildlife Service, National Reservoir Research Program, East Central Reservoir Investigations (ECRI), Bowling Green, Ky., under Interagency Agreement WES 79-04, dated 1 April 1980. This study forms part of the Environmental and Water Quality Operational Studies (EWQOS) Task IIB, Guidelines for Determining Reservoir Releases to Meet Environmental Quality Objectives. The EWQOS Program is sponsored by the Office, Chief of Engineers (OCE), U. S. Army, and is assigned to the U. S. Army Engineer Waterways Experiment Station (WES) under the management of the Environmental Laboratory (EL). OCE Technical Monitors for EWQOS were Mr. Earl Eiker, Mr. James L. Gottesman, and Mr. John Bushman.

This report was written by Mr. Jerry F. Novotny of ECRI and Dr. Robert D. Hoyt of Western Kentucky University, Bowling Green, Ky. Dr. Hoyt also collected and analyzed the zooplankton samples under the direction of ECRI. Preparation of this report took place under the direct supervision of Dr. John Nestler and the general supervision of Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division, EL, and Dr. John Harrison, Chief, EL. Dr. Jerome L. Mahloch was Program Manager, EWQOS.

The Commander and Director of WES during this study and the preparation of this report was COL Tilford C. Creel, CE. The Technical Director was Mr. F. R. Brown.

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CONTENTS

SEASONAL AND SPATIAL DISTRIBUTION OF ZOOPLANKTON IN A FLOOD CONTROL RESERVOIR AND TAILWATER

PART I: INTRODUCTION

Background

1. Zooplankton (Microcrustacea and Rotifera) are important food for fish in lentic habitats, but the availability of these organisms to lotic fishes may be quite limited. When available, zooplankton may be an important food source for fish fry (Irvine and Northcote 1982). Most river and stream environments are poorly suited for the production and maintenance of zooplankton populations and normally harbor only small numbers of these organisms, especially microcrustaceans (Hynes 1970). Rotifers, however, may occasionally be abundant in running waters and dominate a lotic zooplankton community (Winner 1975).

2. Abundance of zooplankton in flowing waters decreases as the current velocity increases. Therefore, zooplankton abundance in a flowing water community is characteristically dependent on the availability of adjacent quiet-water areas that may serve as refuges for survival and production (Hynes 1970).

3. Most tailwater zooplankton are produced in the upstream reservoir. Consequently, the taxonomic composition and seasonal abundance of tailwater zooplankton are dependent on the reservoir community (Brook and Woodward 1956, Maciolek and Tunzi 1968). Some organisms may be produced in backwaters and other quiet-water areas in the tailwater, but the contribution from these locations is seldom significant.

4. The temporal and spatial distributions of zooplankton in reservoirs depends upon seasonal and reservoir hydraulic conditions. Reservoir zooplankton communities vary seasonally in abundance and composition in response to changing light, temperature, food availability, and predation. In addition, abundances are influenced by the hydraulic residence time of a reservoir: densities are higher in reservoirs with

extended hydraulic residence times, since zooplankton are unable to complete a life cycle before being discharged from reservoirs with short hydraulic residence times.

5. The number of zooplankton passed into a tailwater is highly dependent on the depth of release from the reservoir, since zooplankton are not uniformly distributed with depth in stratified reservoirs. Also, the vertical migration of zooplankton within the water column, which occurs in response to changes in light intensity, may keep the organisms away from the withdrawal level of the reservoir during certain periods of the day. Novotny and Faler (1982) related diel changes in Barren River Lake, Kentucky, tailwater zooplankton densities to stratification in the reservoir. Diel densities in the tailwater fluctuated when the reservoir was unstratified but remained relatively unchanged during stratification. The authors concluded that zooplankton were migrating through the level of discharge during unstratified conditions but were not actively penetrating the anoxic hypolimnion during stratification.

6. Zooplankton abundance may also be altered in tailwaters below selective withdrawal dams where changes in the level of release are made in response to rainfall or seasonal management schemes. Discharges from deep-withdrawal reservoirs are not as rich in planktonic organisms as those from surface or midlevel releases (Ward 1975). Zooplankton are normally concentrated in the upper levels of a body of water and may be suspended in the water column above the level of release; those present in the discharges of deep withdrawals are primarily moribund or dead organisms which have settled into the lower levels of the reservoir (Coutant 1963).

7. Zooplankton transported into the tailwater from the reservoir provide a more readily available source of energy and protein for tailwater biota than does the detritus normally found in unregulated streams (Armitage 1978). The zooplankters, associated organisms (such as ichthyoplankton), and nutrients that are flushed into the tailwater may be expendable in terms of overall productivity of the reservoir but may contribute heavily to the trophic status of a tailwater (Hudson and Lorenzen 1980). Surface withdrawals from upper strata in the reservoir

water column can release large numbers of live zooplankton; the moribund or dead organisms in deep releases contribute to the total organic load and thus provide a source of nutrient-rich detritus to the tailwater (Armitage and Capper 1976). Seasonal inconsistencies in reservoir discharge can, however, preclude zooplankton from being a reliable source of either nutrients or food for tailwater organisms (Ward 1975).

8. Densities of zooplankton decrease progressively downstream after discharge into the tailwater (Chandler 1937, Ward 1975, Kallemeyn and Novotny 1977). This decrease is due to a combination of factors including the abundance of zooplankton discharged, filtering effects of periphytic or macrophytic vegetation in the tailwater, physical destruction, predation, and adherence to or ingestion of silt and debris (which causes the organisms to sink).

Purpose and Scope

9. A year-long study was conducted at Barren River Lake, Kentucky, to determine the effect of normal, seasonal, flood control operation of a nonhydropower reservoir on the downstream transport of zooplankton (microcrustaceans and rotifers). The export of Barren River Lake zooplankton to the tailwater was quantified on an annual basis, and the density of zooplankton at successive sites downstream from the dam was determined. The spatial and temporal distributions of tailwater zooplankton were then related to reservoir operation to identify project-related factors that act to significantly alter the distribution of zooplankton in the tailwater.

PART II: STUDY AREA, SAMPLING METHODS, AND ANALYSIS TECHNIQUES

10. Barren River Lake is a multilevel discharge, flood control reservoir located in south-central Kentucky. At "seasonal pool" (April through September), the lake elevation is maintained at 168 m above mean sea level (msl) and the surface area is 4047 ha; at minimum pool (October through March), lake elevation is 160 m above msl and the surface area is 1757 ha. Discharges average 37.8 m^3/sec during seasonal pool and 74.5 m^3/sec during minimum pool. Water can be released from three reservoir levels: two upper level bypass ports release water from an elevation of 162 m and 156 m above msl, and the main floodgate at the base of the discharge tower releases water from an elevation of 147 m above msl. Other information on the reservoir and tailwater is given by Walburg et al. (1983).

11. Zooplankton were collected in the Barren River Lake reservoir and at three stations in the river below the dam (Figure 1). The reservoir station was located about 200 m above the dam, near the discharge tower; depth at this station ranged from 8 m at minimum pool to 21 m at maximum pool. The tailwater stations were about 0.3-0.5 km (Station 1), 10 km (Station 2), and 22 km (Station 3) below the dam (Figure 1).

12. Reservoir strata were identified from temperature and dissolved oxygen readings at successive 1-m depths as determined with a Yellow Springs Instrument (YSI) Model 54 oxygen meter.

13. Temperature, dissolved oxygen concentration, and stream velocity were measured at each tailwater station on each sampling date. Temperature and oxygen were determined with the YSI oxygen meter, and current speed was determined with a General Oceanics flowmeter (Model 2030). Estimates of current speed were based on an average of three flowmeter readings taken near the mouth of each plankton net. Rate and depth of reservoir discharge were provided by the U. S. Army Corps of Engineers, Barren River Lake.

14. Plankton samples were collected from Barren River Lake and each of the tailwater stations between 1000 and 1400 hr during the second and fourth week of each month from August 1980 to August 1981. Reservoir

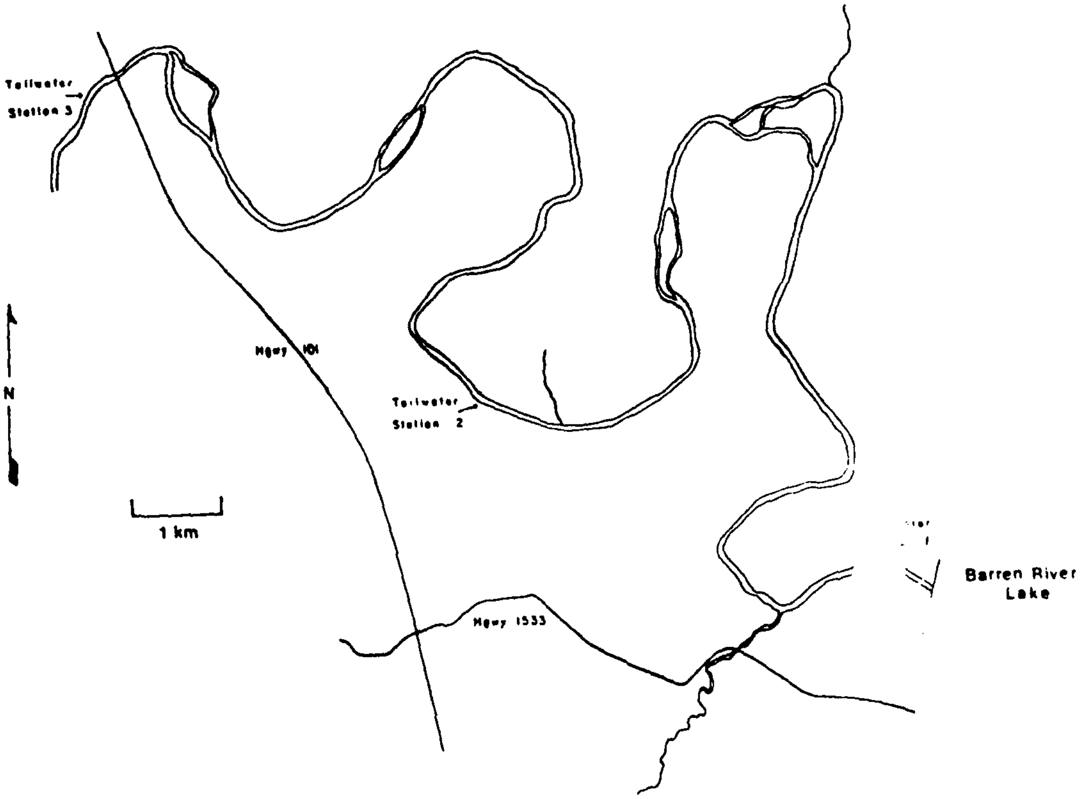

Figure 1. Barren River Lake tailwater, showing locations of tailwater sampling stations

samples were taken with a Clarke-Bumpus sampler (0.74-mm-mesh net). Paired vertical tows were taken separately in the epilimnion, the metalimnion, and the hypolimnion during stratification and from the bottom to the surface during unstratified periods. After each tow, the net was washed with tap water and the organisms collected were fixed in Lugol's solution.

15. In the tailwater, plankton samples were taken with paired 0.074-mm-mesh nets anchored to a concrete base. Each net had a 15-cm-diameter mouth and was 1 m long. Nets were set for 1 to 5 minutes, depending on the debris load in the water. Organisms were washed from the nets and fixed in Lugol's solution. The volume of water sampled was

determined by multiplying the area of the net mouth, the current velocity, and the sampling time.

16. In the laboratory, field samples were concentrated and suspended in 50 mL of water. Organisms in three 1-mL subsamples were counted and identified from each 50-mL dilution. However, if fewer than 50 specimens were found in each 1-mL subsample, the total sample was counted. Densities of organisms (no./m^3) were determined by combining the estimated total numbers in both nets and dividing that number by the total volume of water that passed through the nets. Differences in zooplankton densities among the sampling locations were compared statistically using a randomized, complete block analysis of variance and Tukey's mean separation technique (Steel and Torrie 1980).

PART III: RESULTS

17. Barren River Lake usually begins to stratify by early May and remains stratified through September (Charles and McLemore 1973; East Central Reservoir Investigations, unpublished data). During the present study, weak stratification developed in late May in 1981, but a sharp temperature break between the epilimnion and metalimnion did not develop (Figure 2). The 1981 stratification pattern was altered by heavy rainfall in the drainage basin and subsequent increases in discharge through the main flood-release gate at the bottom of the operating tower (147 m above msl). During most of the study, releases were from the bottom gate or the midlevel bypass port (156 m above msl). The level from which water was discharged determined water temperatures in the tailwater, especially near the dam.

18. Water in the hypolimnion was anoxic in August and September 1980 and August 1981. During all other months, dissolved oxygen (DO) concentrations in the reservoir seldom were below 3 mg/L (Figure 2). In June 1981, DO values as low as 1 and 2.5 mg/L were observed at depths greater than about 3 m. Anoxic conditions were not observed in the tailwater since water from the hypolimnion was reaerated during passage through the outlet works.

19. Average annual water temperatures at the three tailwater stations were similar; however, temperatures at Station 1 were lower in the summer and higher in the winter than at the two downstream stations. Dissolved oxygen concentrations measured at the three tailwater stations were never lower than 5 mg/L, which is considered adequate for maintenance of aquatic life.

20. Cladocera, Cyclopoida, Calanoida, and Rotifera were the four major taxa collected. Other organisms, including aquatic insects, arachnids, and oligochaetes, were occasionally taken but were not included in the analysis.

21. Mean annual densities of the three microcrustacean taxa (Cladocera, Cyclopoida, and Calanoida) were highest in the reservoir and progressively decreased in the tailwater from Station 1 to Station 3

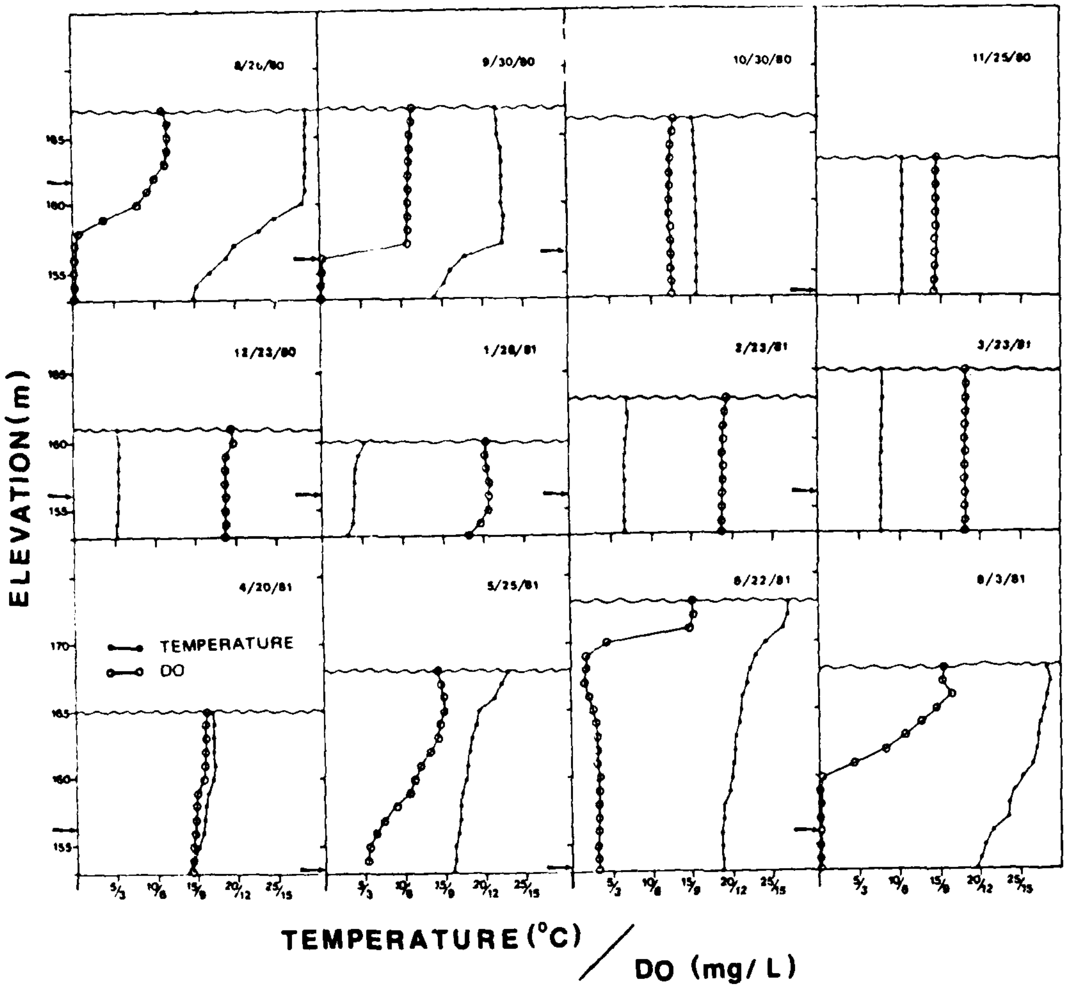

Figure 2. Monthly temperature and dissolved oxygen (DO) profiles taken in Barren River Lake, August 1980-August 1981 (arrows indicate depth of reservoir discharge, except that discharges depicted as 153 m above msl (25 November 1980 and 25 May and 22 June 1981) were actually from the 147-m level)

(Figure 3). Mean densities of all three taxa seemed much lower than in the reservoir but were not significantly ($p > 0.05$) lower at Station 1--Cladocera by 65 percent, Cyclopoida by 52 percent, and Calanoida by 38 percent. The differences were not significant, primarily because large numbers of Cladocera and Cyclopoida were collected in the lake for only a short period in the spring; densities were more similar during

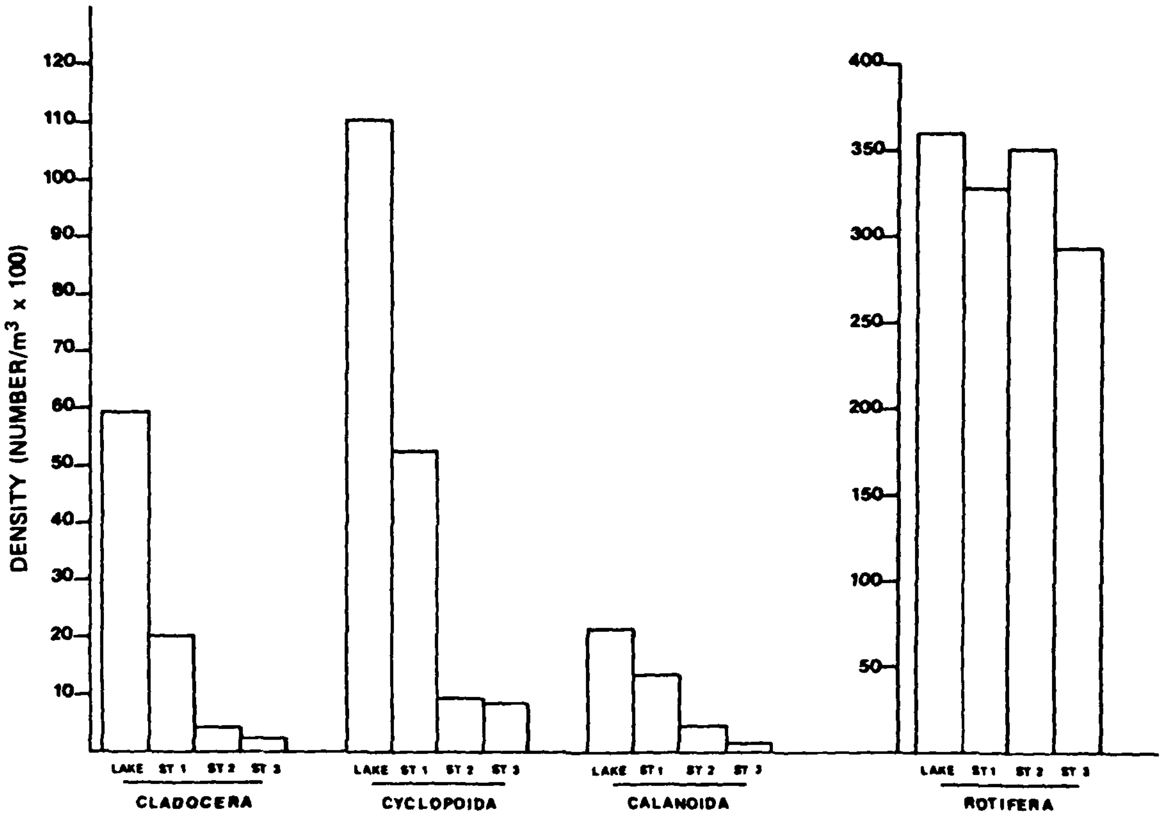

Figure 3. Mean densities of Cladocera, Cyclopoida, Calanoida, and Rotifera in Barren River Lake and at three stations in the tailwater, August 1980-August 1981

other periods. The largest relative difference between successive tailwater stations occurred between Stations 1 and 2; densities of all three taxa were significantly lower (0.01 level) at Station 2. No significant differences (0.01 level) were noted between Stations 2 and 3, and numerical differences between these two stations were slight. Differences in rotifer abundance among the sampling locations were not significant, although 6 percent fewer rotifers were collected at Station 1 than in the reservoir (Figure 3).

22. Three seasonal peaks in microcrustacean plankton abundance were observed in the reservoir--a 6- to 8-week period of maximum abundance in March-April and moderate peaks in both December and June (Figure 4). Additional observations: densities were higher in the reservoir than in the tailwater throughout most of the year; fewest reservoir microcrustaceans were collected in late July and August 1981; densities were slightly lower in the reservoir than in the tailwater in November. These differences may have (a) reflected sampling error due to diurnal movement of zooplankton in the reservoir or (b) indicated congregation in the area of discharge. Since the reservoir tow during nonstratification was a composite for all depths, it was impossible to determine in which strata the plankters were located during sampling.

23. The peak densities of microcrustaceans at Station 1 occurred concurrently with peak densities in the reservoir. Most were collected in March and April and fewest in late July and August 1981. Densities at Stations 2 and 3 were always reduced, and there was no relation among seasonal changes in either the reservoir or at Station 1. Densities at Station 2 (not shown in Figure 4) were usually intermediate between those at Stations 1 and 3.

24. In March and April, discharges from Barren River Lake were low (about 3 m^3/sec), water temperatures were rising (from 8 to 17°C), and microcrustacean densities were at their highest in both the reservoir and at Station 1. Discharges during this period were more stable, and lower, than at any other time of year. During other months, changes in densities of microcrustaceans in the tailwater appeared unrelated to fluctuations and volume of reservoir discharge (Figure 4).

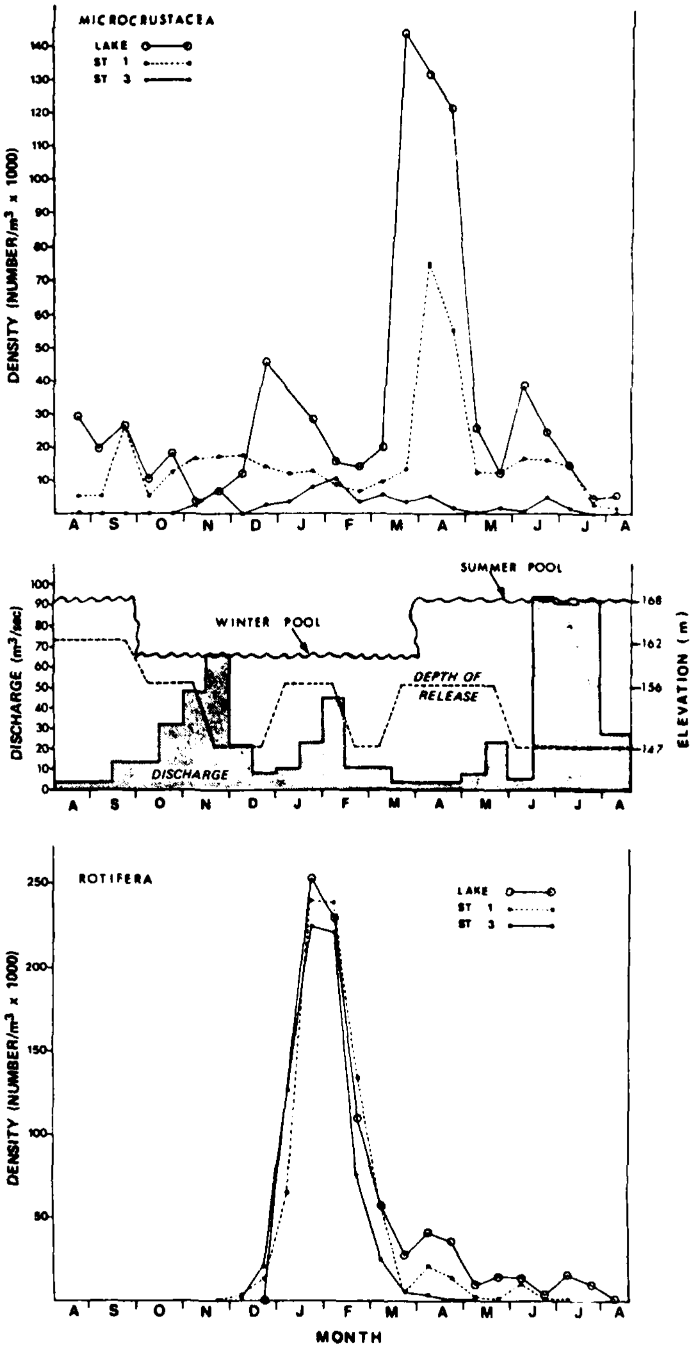

Figure 4. Total densities at 2-week intervals of microcrustacea (upper graph) and Rotifera (lower graph) in Barren River Lake and at Stations 1 and 3 in the tailwater, August 1980-August 1981). Discharge rates and related information during the same time period are shown in center panel

25. Rotifer densities in both the reservoir and tailwater were similar throughout the year; however, on most occasions abundance declined progressively as distance below the dam increased (Figure 4). Densities were highest in January and February, and lowest from March through August. No rotifers were collected in either the reservoir or in the tailwater during August, September, October, or early November in 1980. During the period of maximum rotifer abundance, reservoir discharges were relatively unstable, fluctuating between 10 and 44 m^3/sec, and water temperatures were generally lower (4-7°C) than at any other time of year.

26. A distinction between zooplankton densities in the epilimnion and metalimnion was difficult to determine; therefore, these strata were combined into one unit for comparison with densities in the hypolimnion. The following tabulation shows mean numbers per cubic metre of microcrustaceans and rotifers in the epilimnion-metalimnion of Barren River Lake and at Station 1 on seven sampling dates during reservoir stratification.

Taxa	Epilimnion-Metalimnion	Hypolimnion	Tailwater Station 1
Cladocera	7,097	1,626	2,443
Cyclopoida	3,414	2,355	3,224
Calanoida	2,850	554	928
Rotifera	10,185	541	1,624

All four zooplankton groups were concentrated in the upper strata of the reservoir during stratification. Differences between the epilimnion-metalimnion stratum and the hypolimnion were largest for Cladocera and the rotifers; densities of these organisms were also much higher than for either the Cyclopoida or Calanoida in the upper stratum. The abundances of all four groups at tailwater Station 1 during stratification were higher than those in the hypolimnion, but lower than those in the epilimnion-metalimnion.

PART IV: DISCUSSION AND CONCLUSIONS

27. Barren River Lake exports a significant quantity of reservoir zooplankton to the tailwater. The potential influence of these organisms on tailwater biota has been discussed by Chandler (1937), Armitage and Capper (1976), Hudson and Lorenzen (1980), and Novotny and Martin (1980). In the tailwater, these organisms may be eaten by other invertebrates and fish, or may be a source of nutrients when they die and decompose (Gibson and Galbraith 1975, Armitage and Capper 1976). Although direct evidence is not presented, the reservoir zooplankton losses may have a similar effect on the Barren River Lake tailwater.

28. The entire water column was potentially available to zooplankton during nonstratification. The levels of withdrawal, however, were below the levels of main concentrations of organisms during most periods, resulting in lower plankton densities in the tailwater than in the reservoir water column.

29. During reservoir stratification, densities of zooplankton in the tailwater were higher than in the hypolimnion, suggesting that organisms from upper levels in the reservoir, as well as from the hypolimnion, were being discharged into the tailwater. Apparently, some of the water in the discharge came from reservoir strata above the release level (water was released from 156 m above msl, and occasionally from the main flood-release gate). A withdrawal plume may have formed near the discharge tower intake ports that included water from both above and below the actual level of withdrawal. The shape and extent of such a plume would have been determined by intake port design, the effects of inflowing waters, reservoir discharge volume, and density differences within the reservoir (Wunderlich 1971).

30. Microcrustacean zooplankton densities in the tailwater are reduced by physical destruction and fragmentation during downstream transport (Ward 1975). Additional decreases in densities are caused by fish predation resulting from the high concentration of fish in the tailwater, which reach densities of 7870 to 8518/ha in winter and spring (East Central Reservoir Investigations, unpublished data). The most common

species in the tailwater was the gizzard shad (*Dorosoma cepedianum*), which filters plankton for food (Bodola 1966). Abundance of this species in Barren River Lake has been inversely correlated with microcrustacean densities (Martin and Stroud 1973).

31. The gradual reduction in microcrustacean densities that occurred between tailwater Stations 1, 2, and 3 was apparently due to continued predation and the lack of a habitat in which the organisms could survive once they were flushed into the tailwater. Lotic habitats are not suitable for the maintenance of microcrustacean populations, and their abundance in unregulated running waters is inversely related to current speed (Hynes 1970). Therefore, high flows in the tailwater should decrease densities rather than simplv carry the organisms farther downstream. In this study, there appeared to be no relation between increases in discharge and densities of either microcrustaceans or rotifers in the tailwater. These findings are in agreement with earlier (1968-71) studies in this tailwater, in which plankton densities were shown to fluctuate independently of the discharge regime (Martin and Stroud 1973).

32. Long periods of water retention in a reservoir result in increased production and higher plankton densities (Brook and Woodward 1956, Coutant 1963). The rates of flow through a reservoir may therefore be as important as the depth of discharge in determining numbers of plankters entering a tailwater. Higher densities measured during the period when discharges were low and associated water-retention times in the reservoir increased may have resulted from the longer water-retention times. However, since peak densities occur in early spring in many reservoirs regardless of the discharge regimes, the high densities in Barren River Lake and tailwater during low spring flows may have been simply coincidental or related to destratification and associated increases in phytoplankton biomass.

33. Progressive reductions in downstream microcrustacean densities have also been attributed to the filtering effects of aquatic vegetation in the tailwater and to the ingestion of sand and silt by the organisms during transport, which would tend to cause them to sink rapidly as they proceed down the tailwater (Chandler 1937, Ward 1975, Armitage and

Capper 1976). The Barren River Lake tailwater, however, is relatively devoid of aquatic vegetation, and discharges are not highly turbid (1.0-3.9 NTU (East Central Reservoir Investigations, unpublished data)).

34. Most rotifers were collected in January and February when reservoir levels were low and the depth of withdrawl was relatively near the surface. Rotifer abundance was similar in the reservoir and tailwater, especially during January and February. Rotifers were more persistent than larger zooplankters in the tailwater; they were present in relatively high densities at all three tailwater stations with little decrease downstream. Larger zooplankters (primarily microcrustaceans) are normally selected as fish food before smaller organisms (primarily rotifers) simply because they are larger (Brooks and Dodson 1965); they are also the first to be destroyed by adverse physical conditions in tailwaters (Ward 1975). The persistence of rotifers in the tailwaters may thus have been a result of their small size which made them largely inaccessible as prey and allowed them to survive turbulent flows. Additionally, the survival rate during passage through the dam of the different major taxa of zooplankton may vary.

35. In sum:

<u>a</u>. Overall densities of zooplankton in the Barren River Lake tailwater are related to hydraulic residence time in the reservoir, degree of thermal and chemical stratification in the reservoir, depth of withdrawal, seasonal abundance pattern of zooplankton in the reservoir, and extent of vertical migration of zooplankton relative to the depth of withdrawal.

<u>b</u>. Depletion of reservoir zooplankton in the tailwater is relatively gradual. Some groups are carried at least 22 km downstream from the dam in substantial numbers.

<u>c</u>. Depletion of reservoir zooplankton in tailwaters results from predation, lack of habitat, settling because of ingestation of or adherence to silt, physical destruction, and filtering effects of aquatic vegetation.

36. It can therefore be concluded that implementation of operational procedures to increase discharge of reservoir zooplankton to the tailwater may not be warranted since the complexity of factors determining reservoir zooplankton dynamics precludes their use as a reliable food source for tailwater biota.

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