EPA-600/3-78-020
February 1978

Ecological Research Series

BROWNS FERRY BIOTHERMAL RESEARCH SERIES
I. Colonization by Periphyton, Zooplankton, and Macroinvertebrates

Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Duluth, Minnesota 55804

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ECOLOGICAL RESEARCH series. This series describes research on the effects of pollution on humans, plant and animal species, and materials. Problems are assessed for their long- and short-term influences. Investigations include formation, transport, and pathway studies to determine the fate of pollutants and their effects. This work provides the technical basis for setting standards to minimize undesirable changes in living organisms in the aquatic, terrestrial, and atmospheric environments.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/3-78-020
February 1978

BROWNS FERRY BIOTHERMAL RESEARCH SERIES
I. COLONIZATION BY PERIPHYTON, ZOOPLANKTON, AND MACROINVERTEBRATES

by

Brian J. Armitage, Thomas D. Forsythe,
Elizabeth B. Rodgers, and William B. Wrenn

Biothermal Research Section
Division of Forestry, Fisheries, and
Wildlife Development
Tennessee Valley Authority
Decatur, Alabama 35602

TV-35013A

Project Officers

Thomas H. Ripley
Division of Forestry,
Fisheries, and Wildlife Development
Forestry Building
Norris, Tennessee 37828

Kenneth E. Biesinger
Environmental Research Laboratory
6201 Congdon Boulevard
Duluth, Minnesota 55804

This study was conducted
in cooperation with
Tennessee Valley Authority
Norris, Tennessee 37828

ENVIRONMENTAL RESEARCH LABORATORY - DULUTH
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
DULUTH, MINNESOTA 55804

DISCLAIMER

This report has been reviewed by the Environmental Research Laboratory-Duluth, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The aquatic environment must be protected from the adverse effects of thermal dishcarges. Large volume thermal discharges, if not properly managed, can have deleterious effects on fish populations and their food chain organisms and thus ultimately diminish the quality of man's environment; conversely, excessive control measures can result in economic penalties to the public. A balance must therefore be attained between the industrial utilization of water and the maintenance of a high-quality environment. The Browns Ferry Biothermal Research Station contributes to the search for this acceptable balance through investigations on

--the effects of increased temperature on growth, survival, reproduction of sport and commercially important fish species and their food organisms, and

--the effects of increased temperature on the ecological relationships between fish and their food organisms.

This report focuses on the ecology of organisms in the experimental system which will constitute the food chain for the fish species to be investigated. Specifically, this report addresses the colonization of the experimental system, under natural thermal conditions, by the food chain organisms and thus serves as the baseline for future studies that will be conducted under conditions of elevated temperatures.

Clyde W. Voigtlander
Senior Aquatic Ecologist
Division of Forestry, Fisheries,
and Wildlife Development
Tennessee Valley Authority
Norris, Tennessee 37828

ABSTRACT

Colonization studies on a series of 12 outdoor experimental channels supplied with water from Wheeler Reservoir (Tennessee River) were completed at the Browns Ferry Biothermal Research Station in Alabama. Species composition, dominance, seasonal patterns, colonization rates, and biomass estimates were determined over a 24-month period for periphyton, zooplankton, and macroinvertebrates. The periphyton assemblages were highly productive and diverse. Colonization of bare surfaces was extremely rapid during summer months. Zooplankton was abundant and was composed primarily of shallow-water forms. Macroinvertebrates quickly colonized the biothermal channels by way of inflowing reservoir water and by air. Macroinvertebrate diversity was as great as or greater than that in Wheeler Reservoir and represented taxa found in both littoral and open-water areas. In general, the species composition and the relative densities of algal and invertebrate organisms that colonized the channels indicated that the channels successfully simulate reservoir ecosystems for those trophic levels.

The work upon which this publication is based was performed pursuant to an Interagency Agreement between the Tennessee Valley Authority and the Environmental Protection Agency. This report was submitted in partial fulfillment of Contract No. TV-35013A by the Tennessee Valley Authority under partial sponsorship of the U.S. Environmental Protection Agency. This report covers field work from March 1974 to February 1976, and analyses completed as of March 1977.

CONTENTS

Foreword iii
Abstract iv
Figures vi
Tables vii

1. Introduction 1
2. Research Facility 2
3. Conclusions 5
4. Periphyton 7
   Scope 7
   Materials and Methods 7
   Results and Discussion 8
5. Zooplankton 19
   Scope 19
   Materials and Methods 19
   Results 21
   Discussion 22
6. Macroinvertebrates 30
   Scope 30
   Materials and Methods 30
   Results 31
   Discussion 32

References 45

FIGURES

Number		Page
1.	Planview of experimental channels and auxiliary facilities	3
2.	Profile of Browns Ferry biothermal experimental channel	4
3.	Number of periphyton species identified from the biothermal channels (plotted by quarterly accumulations)	16
4.	Mean values for active chlorophyll a during the colonization period (15 cm depth)	17
5.	Vertical profiles of active chlorophyll a after 1 and 3 weeks colonization	18
6.	Diel periodicity of *Simocephalus vetulus* (large cladoceran) in a channel during the winter	24
7.	Total microcrustacean plankton density (numbers/m^3) and dry weight biomass (mg/m^3) in a channel for the 1974 and 1975 sampling periods	26
8.	Water temperature and density of the seven dominant taxa in one channel for the 1974 and 1975 sampling periods	27
9.	Species composition in terms of percent numbers and percent biomass for 1974 and 1975 sampling periods	28

TABLES

Number		Page
1.	Algal taxa found in the biothermal channels	10
2.	Increases in the number of algal species colonized after 3, 7, and 10 days	15
3.	Number of algal species colonizing bare substrates at 15, 46, and 76 cm depth	15
4.	Microcrustacean plankton found in channels as of 1975	25
5.	Average percent relative abundance in terms of numbers and biomass in one channel and in terms of numbers in Wheeler Reservoir	29
6.	Macroinvertebrate taxa identified in biothermal channels during colonization period	34
7.	Macroinvertebrate taxa observed in three sample areas on succeeding dates	39
8.	Population trends of taxa sampled in channels between summer, 1974 and spring, 1976	42
9.	Numbers and dry weights of organisms per m^2 on wall areas on successive sampling dates in 1976	44

SECTION 1

INTRODUCTION

As early as 1968, the Tennessee Valley Authority (TVA), in collaboration with the Federal Water Pollution Control Administration, now the Environmental Protection Agency (EPA), recognized the need to acquire scientific information that could be used for reliable prediction of the effects of increased temperature on aquatic organisms. A plan was initiated to build a research facility in which aquatic organisms could be held under essentially natural conditions but maintained under the closer controls that approached laboratory conditions. Construction of this facility, which began in 1972, is essentially complete.

The primary feature of the facility is a series of 12 temperature-controlled outdoor channels. The project objectives are to: (1) Determine the effect of increased annual temperature on the growth, survival, and reproduction of warm-water fishes with emphasis on sport and commercially-valuable reservoir species; (2) determine the effect of increased annual temperature on the species composition and production of algae, macroinvertebrates, and zooplankton; and (3) determine the effect of increased annual temperature on ecological relations between fish and their food organisms. Attainment of the above objectives will provide data for establishing or adjusting temperature criteria for warm-water streams and reservoirs, and for establishing thermal regimes for optimal production of specified groups of aquatic organisms.

Prior to the initiation of the heated water experiments, the channels were colonized by Tennessee River organisms over a three-year period (1974-1976) under ambient temperature conditions. This report documents the establishment of the primary and intermediate trophic levels in the channels during the first 24 months.

SECTION 2

RESEARCH FACILITY

The research station is located adjacent to TVA's Browns Ferry Nuclear Plant on the north bank of the Tennessee River (Wheeler Reservoir), approximately 10 miles (16 km) southwest of Athens, Alabama. Water temperature and flow are controlled in 12 concrete channels (114 m long, 4.3 m wide, and 2 m deep) (Figure 1). The substrates (natural reservoir sediments and limestone rock) are arranged to provide six alternating pools and six rock areas in each channel (Figure 2). Other major components include: six tubular heat exchangers located near the inlets of the channels; high-temperature and low-temperature pumping stations; five secondary fish-holding ponds; a laboratory-office building; and a water-quality monitoring system that includes a minicomputer (32-K memory).

For this 24-month colonization study, water was pumped to the channels from Wheeler Reservoir at the same rate as that at which it will be pumped for the heated water experiments. Water discharge is about 0.66 m^3/min (180 gal/min) with a channel retention time of approximately 14 hours.

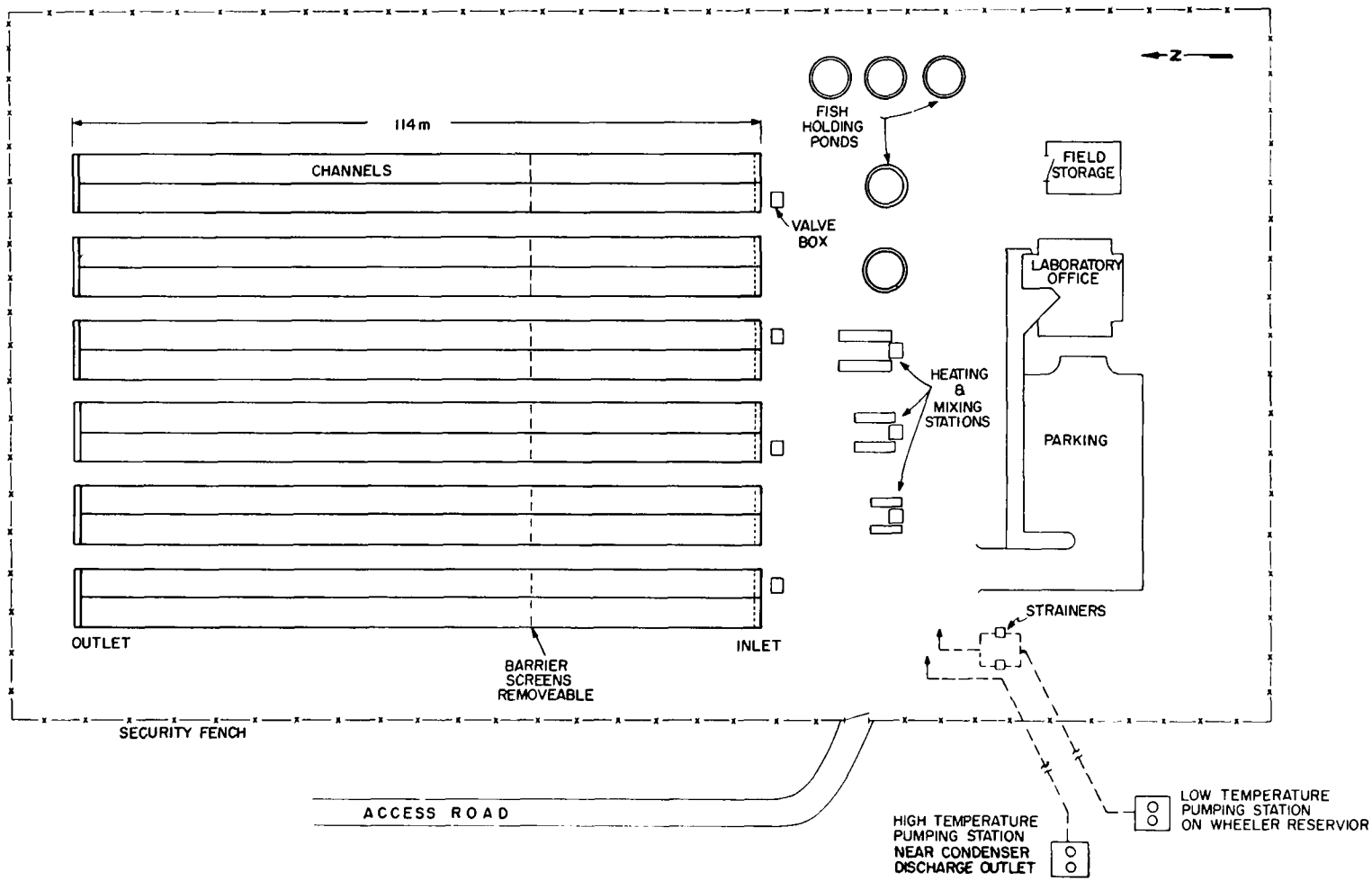

Figure 1. Planview of experimental channels and auxiliary facilities.

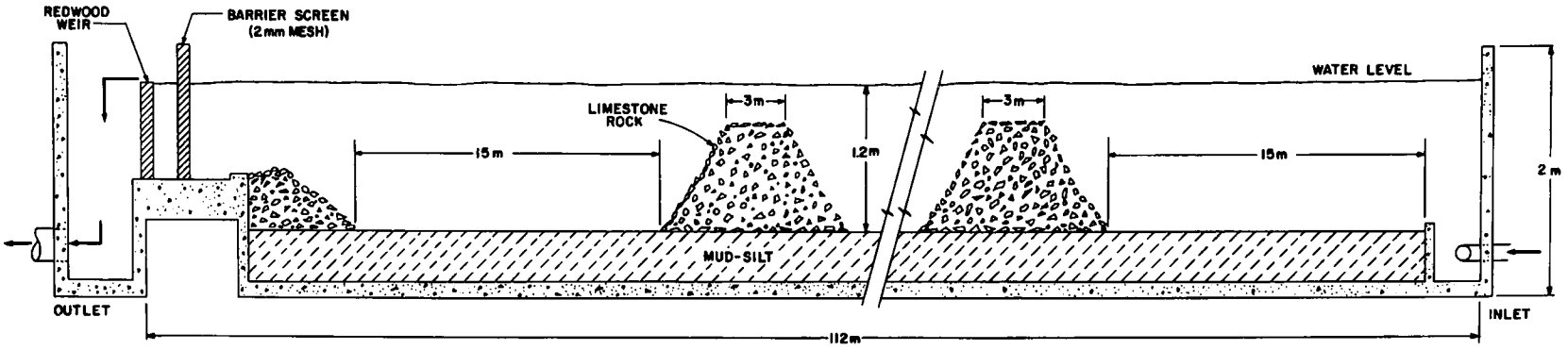

Figure 2. Profile of Browns Ferry biothermal channel.

SECTION 3

CONCLUSIONS

On the basis of 24 months of colonization studies and observations, we have derived the following conclusions concerning the non-chordate biota of the biothermal channels:

1. Initial filling of the channels was accompanied by high algal productivity and biomass.

2. Chlorophyll a concentrations of periphyton on wall and rock areas were highest during the late summer and early fall.

3. The biomass (as chlorophyll a) and species richness of the periphyton were within ranges reported in the literature.

4. Colonization rates were greater during the summer in terms of both species numbers and biomass.

5. Zooplankton community composition became more complex as colonization proceeded; seven groups (*Simocephalus*, daphnids, *Bosmina*, *Ceriodaphnia*, cyclopids, *Chydorus*, and ostracods) were dominant.

6. The channels are selective for shallow-water zooplankton species. No established populations of open-water forms were found.

7. The channel design allows convenient sampling of zooplankton, although the diel periodicity patterns of most species necessitate night sampling.

8. The biothermal channels provide excellent habitat for colonization or macroinvertebrate species native to the Tennessee River.

9. Pool areas in the channels are suitable for invasion by *Hexagenia bilineata*, bivalve molluscs including *Corbicula manilensis*, *Anodonta imbecilis*, and *Eliptio crassidens*; relatively large operculate gastropods such as *Pleurocera canaliculatum*; the leech, *Erpobdella punctata*; and certain midges of the subfamily Chironominae. All of these organisms are found also in open-water benthic areas of Wheeler Reservoir.

10. Rock and wall areas offer suitable habitat for the amphipods *Hyalella azteca* and *Crangonyx* sp., relatively small pulmonate and operculate Gastropoda, heptageniid and baetid Ephemeroptera, psychomyiid and hydroptilid Trichoptera. and a wide variety of Odonata and Chironomidae.

11. Organisms dominant in terms of numbers were the Oligochaeta, Pelecypoda, Amphipoda, Gastropoda, and Chironomidae.

12. Channels drawn down for two months in late fall successfully recolonized. Gastropoda, Amphipoda, and Chironomidae showed definite increased densities after drawdown.

SECTION 4

PERIPHYTON

SCOPE

The biothermal channels are similar to the littoral areas of many reservoirs, because of water depth and substrate types. The absence in the channels of aquatic vascular plants and of extreme wave activity are the apparent principal differences. In water bodies with well-developed littoral zones, the attached algae usually contribute a major share of the annual productivity of the system (Hutchinson, 1975; Wetzel, 1975). Species diversity is also usually high, with species lists commonly showing 100-300 species present in the littoral zones (Hutchinson, 1975). Beginning in June, 1974, an evaluation was undertaken of the periphyton naturally colonizing the biothernal channels. The purposes of the initial colonization studies were: (1) to determine species composition and dominance patterns; (2) to identify seasonal shifts and cycling in the periphyton community; (3) to estimate species invasion rates and ascertain the sequence in which species became established; and (4) to estimate the biomass of periphyton produced with time.

MATERIALS AND METHODS

Samples for species identification were taken from scrapings of walls and rock areas, from floating mats, from cores of pool sediments, and from artificial substrates (cellulose acetate strips, plexiglas plates, glass slides, styrofoam sheets). Identifications were made to the species level whenever possible.

Colonization of artificial substrates was compared with that of natural substrates in the channels. Although periphyton assemblages on all artificial substrates tested approximated those on natural substrates, cellulose acetate was slightly superior. This material had the additional advantage of being easy to cut in various dimensions. Therefore, the major portion of the results was obtained employing this material. Strips (5 cm x 50 cm) were suspended horizontally at a depth of 15 cm and allowed to be colonized for two, three, and four weeks. Smaller strips (2.5 x 5 cm) were implanted in rubber stoppers and suspended at depths of 15, 46, and 76 cm. Long strips (2.5 x 105 cm) were also hung vertically in the water column for pigment-depth profiles.

Species invasion sequences were interpreted on a presence/absence basis. Three-dimensional colonies, branched filaments, mucilaginous colonies, tapering filaments, and dividing mother cells complicated attempts at quantification

either by cell counts or cell volumes. Recent experiments using tetrazolium violet have indicated that a significant number of algae colonizing artificial substrates (which would normally be counted using conventional microscopic techniques) were not metabolically active. Tetrazolium violet is a tetrazolium salt which forms a violet precipitate in actively metabolizing cells via the electron transport system (Dozier, OREL, unpublished). The 2.5 x 5.0 cm strips for species invasion sequences were normally collected after 3, 7, and 10 days. Species invasion sequences and colonization rates were examined periodically.

Chlorophyll was analyzed following methods of EPA (1973) and Vollenweider (1974). Correction was applied for phaeophytin. Active chlorophyll a is reported as μg chl a*/cm^2.

RESULTS AND DISCUSSION

During 1974-75, 124 taxa of algae were identified (Table 1). Of these, 100 taxa were identified to the species level (greens [36], charophytes [1], euglenoids [2], diatoms [55], blue-greens [6]). Most of these taxa were epilithic or epiphytic; the epipelic taxa received only a cursory examination. Although the absence of aquatic vascular plants in the channels has possibly eliminated an important habitat normally present in the littoral zones of lakes and reservoirs, the diversity of algae colonizing the biothermal channels is comparable with that of many reservoirs.

During spring 1974, following the initial filling of the channels with water pumped from Wheeler Reservoir, massive blooms of *Hydrodictyon reticulatum* developed in the channels. Floating mats of this species eventually concentrated at the lower ends of the channels. Following this bloom, smaller random blooms of *Spirogyra gratiana, Sp. nitida,* and *Cladophora glomerata* occurred along the walls or on the rock areas. Very few diatom species were in evidence. The periphyton community during winter 1974-75, was dominated by *Oedogonium kurzii, Stigeoclonium* sp., and a few epilithic and epiphytic diatoms (*Melosira varians, Cocconeis disculus, Synedra acus*) were subdominants. These eventually gave way to other filamentous and coccoid green algae of insignificant biomass during early spring. A brief bloom of *Hydrodictyon reticulatum* occurred in several channels during May 1975; however, its intensity and duration were well diminished, compared with the 1974 bloom. Concurrent with the restricted bloom of *Hydrodictyon, Spirogyra gratiana* and *Sp. nitida* began to form mats attached to the walls and rock areas. These species attained their greatest biomass in late August and September 1975. Because of silt accumulation on the *Spirogyra* filaments (probably attracted to an extracellular polysaccharide excreted by these species), the mats became denser and more closely appressed to the substrates. Subsequently, diatoms colonized the silt surface, followed by blue-greens. Occasionally during the summer, random patches of *Cladophora glomerata* appeared, and *Chaetophora elegans* was codominant with *Spirogyra* on substrates exposed during September. The demise of *Spirogyra* paralleled dropping temperatures during October and November. Scrapings from artificial and natural substrates during October-December 1975 were dominated by *Melosira varians* and *Oedogonium kurzii.*

From March 1974 to December 1975, the number of species identified increased in a predictable fashion (Figure 3). The number of diatom species was not appreciable, however, until winter 1975. Desmids also were quite scarce until late summer 1975. Constant introduction of species from the reservoir should add to the channels' flora in forthcoming seasons. The absence of vascular aquatic plants and the annual drawdown of the channels prior to a new experiment, however, could limit the expected increase of species numbers.

The sequence of colonization in summer and winter 1975 varied not only in the species present but also in the number of species and in the rates of colonization (Table 2). During the summer an artificial substrate was coated first by bacteria. This was followed by colonization by a few species of diatoms (*Achnanthes linearis, Gomphonema parvulum, Nitzschia palea*) and coccoid greens. Prostrate colonies of *Protoderma viride* and *Stigeoclonium* sp. then covered large areas, concomitant with the appearance of filaments of *Spirogyra* spp. *Chaetophora elegans* often served as the codominant with *Spirogyra* spp. during the late summer. The winter colonization was also initiated by bacteria but was followed by 15-20 different species of diatoms, particularly *Cymbella tumida, Cym. turgida, Gomphonema angustatum, Melosira varians, Nitzschia acicularis,* and *Synedra acus*. *Melosira varians* clearly dominated the periphyton assemblage after 5-7 days of exposure. After about two weeks of exposure, *Oedogonium kurzii* began to colonize the substrates, eventually dominating or codominating with *M. varians*. Examination of natural substrates revealed an assemblage of periphyton virtually identical with that on artificial substrates. *Oedogonium kurzii* supported an epiphytic diatom flora, in contrast with the summer species of *Spirogyra* whose mucilaginous excretions barred such exploitations.

Chlorophyll a, corrected for phaeophytin (chl a*), was the major biomass estimator during the 1974-75 colonization period. Variation among channels was often high, possibly due to differences in flow rates for each channel. Most chlorophyll samples were taken from artificial substrates that were allowed to be colonized for two weeks (Figure 4). No statistically significant variation ($P > 0.05$) was noted among replicates (3-9) within any one channel. Typical vertical profiles for chl a* and species numbers for the summer months are shown in Figure 5 and Table 3, respectively. Winter profiles were more uniform and fewer species were present.

In general, the productivity of new water bodies is initially high, due to the influence of organic matter and nutrients originating from flooded substrates (Zhadin and Gerd, 1961; Rodhe, 1964; Leentvaar, 1966; Biswar, 1969; Funk and Gaufin, 1971). The biothermal channels were no exception to this "hay-infusion" phenomenon, as evidenced by the extensive mats of *Hydrodictyon reticulatum* and *Spirogyra* spp. Chlorophyll a concentrations of epilithic periphyton attached on walls and rock areas fell within the expected range (100-1200 mg chl a / m^2) suggested by Hutchinson (1975). The species richness also was normal for a littoral habitat. Although some variations existed among channels in terms of biomass, the species and dominance patterns for the channels were relatively consistent. This consistency should provide a good foundation for judging the effects of various thermal regimes upon the periphyton communities.

TABLE 1. ALGAL TAXA FOUND IN THE BIOTHERMAL CHANNELS

Class	Order	Species
Chlorophyceae		
	Volvocales	
		Chlamydomonas sp.[a]
		Pandorina morum Bory
	Tetrasporales	
		Gloeocystis gigas (Kuetz.) Lagerheim
		Palmodictyon viride Kuetzing
	Chlorococcales	
		Ankistrodesmus falcatus (Corda) Ralfs
		Characium ambiguum Herman
		Chlorococcum humicola (Nag.) Rabenh.
		Chodatella quadriseta (Lemm.) G.M. Smith
		Hydrodictyon reticulatum (L.) Lagerheim
		Pediastrum duplex var. *gracilimum* West & West
		Pediastrum simplex (Meyen) Lemmermann
		Scenedesmus quadricauda (Trup.) de Berb.
	Ulotrichales	
		Microspora stagnorum (Kuetz.) Lagerheim
		Stichococcus subtilis (Kuetz.) Klercher
		Ulothrix zonata (Weber & Mohr) Kuetzing
	Chaetophorales	
		Chaetophora elegans (Roth) C.A. Agardh
		Microthamnion sp.
		Protoderma viride Kuetzing
		Stigeoclonium sp.
	Oedogoniales	
		Oedogonium kurzii Zeller

[a] Exact species unknown due to the absence of certain essential diagnostic characteristics.

Class	Order	Species
Chlorophyceae		
	Siphonocladales	
		Cladophora glomerata (L.) Kuetzing
	Zygnematales	
		Mougeotia sp.
		Spirogyra gratiana Transeau
		Spirogyra nitida (Dillw.) Link
		Spirogyra sp.
		Closterium lunula Nitzsch.
		Closterium moniliferum Ehrenb.
		Cosmarium botrytis var. *tumidum* Wolle
		Cosmarium exiguum Arch.
		Cosmarium margaritatum (Lund.) Roy & Bliss
		Cosmarium ochthodes var. *amoebum* West & West
		Staurastrum botrophilum Wolle
		Staurastrum orbiculare Ralfs
		Staurastrum paradoxum W. West
		Staurastrum turgescens de Not
Charophyceae		
	Charales	
		Chara schweinitzii A. Braun
Euglenophyceae		
	Euglenales	
		Euglena sp.
		Phacus orbicularis Huebner

TABLE 1 (continued)

Class	Order	Species
Bacillariophyceae		
	Eupodiscales	
		Cyclotella stelligera Cleve & Grun
		Melosira distans var. *humilis* A. Cleve
		Melosira granulata (Ehrenb.) Ralfs
		Melosira granulata var. *angustissima* O. Mull.
		Melosira varians C. A. Agardh
		Stephanodiscus astrea var. *minutula* (Kuetz.) Grun.
	Fragilariales	
		Asterionella formosa Hassal
		Diatoma hiemale (Roth.) Heib.
		Fragilaria construens (Ehrenb.) Grun.
		Fragilaria crotonensis Kitton
		Opephora martyi Herib.
		Synedra actinastropides Lemmermann
		Synedra acus Kuetzing
		Synedra rumpens Kuetzing
		Syndra ulna (Nitzsch.) Ehrenberg
		Synedra ulna var. *longissima* (W. Smith) Brun.
		Tabellaria fenestrata (Lyngb.) Kuetzing
		Tabellaria flocculosa (Roth.) *Kuetzing*
	Achnanthales	
		Achnanthes exigua Grun.
		Achnanthes lanceolata var. *dubia* Grun.
		Achnanthes linearis (W. Smith) Grun.

TABLE 1 (continued)

Class	Order	Species
Bacillariophyceae		
	Achnanthales	
		Cocconeis disculus (Schum.) Cl.
		Cocconeis placentula Ehrenberg
		Rhoicosphenia curvata (Kuetzing) Grun. *ex* Rabh.
	Naviculales	
		Frustulia rhomboides (Ehrenb.) Det.
		Gyrosigma spencerii (Quek.) Griff. & Henfr.
		Navicula crucicula (W. Smith) Donk.
		Navicula mutica Kuetzing
		Navicula radiosa Kuetzing
		Navicula sp.
		Pinnularia biceps Greg.
		Pinnularia viridis (Nitz.) Ehrenberg
		Stauroneis anceps Ehrenberg
		Gomphonema angustatum (Kuetz.) Rabenh.
		Gomphonema olivaceum (Lyngb.) Kuetzing
		Gomphonema parvulum Kuetzing
		Gomphonema truncatum Ehrenberg
		Amphora sp.
		Cymbella affinis Kuetzing
		Cymbella minuta Hilse *ex* Rabenh.
		Cymbella prostrata (Berk.) Cl.
		Cymbella tumida (Berb. *ex* Kuetz.) V. H.
		Cymbella turgida Greg.

TABLE 1 (continued)

Class	Order	Species
Bacillariophyceae		
	Nitzschiales	
		Nitzschia acicularis W. Smith
		Nitzschia dissipata (Kuetz.) Grun.
		Nitzschia palea (Kuetz.) W. Smith
		Nitzschia sigma W. Smith
		Nitzschia tryblionella Hantzsch.
		Nitzschia vermicularis (Kuetz.) Grun.
		Nitzschia sp.
	Surirellales	
		Cymatopleura solea (Berb.) W. Smith
		Surirella angustata Kuetzing
		Surirella patella Ehrenberg
		Surirella patella var. *neupaueri* (Pant.) Cleve-Euler
		Surirella sp.
Cyanophyceae		
	Chroococcales	
		Merismopedia punctata Meyen
	Oscillatoriales	
		Oscillatoria geminata Menegh.
		Oscillatoria lacustris (Kleb.) Geitler
		Oscillatoria nigra Vaucher
		Oscillatoria princeps Vaucher
	Nostocales	
		Plectonema nostocorum Bornet

TABLE 2. INCREASE IN THE NUMBER OF ALGAL SPECIES COLONIZED AFTER 3, 7, AND 10 DAYS

	Days Exposed	Species $(\bar{x})$[a]	Species (total)[b]	Range
January-	3	16	25	11-19
	7	29	47	24-33
	10	38	59	34-46
July-	3	45	49	39-47
	7	46	58	42-48
	10	52	62	46-57

[a] Mean number of species found on all strips examined (January- 6 channels; July- 4 channels).

[b] Total number of species found on all strips.

TABLE 3. NUMBER OF ALGAL SPECIES COLONIZING BARE SUBSTRATES AT 15, 46, AND 76 CM DEPTH

August-[a]	Depth	Species $(\bar{x})$[b]	Species (total)[c]	Range
	15 cm	31	50	27-35
	46 cm	33	56	28-41
	76 cm	26	42	25-29

[a] Three days colonization period.

[b] Mean number of species found on all strips examined in four channels.

[c] Total number of species found on all strips at each depth.

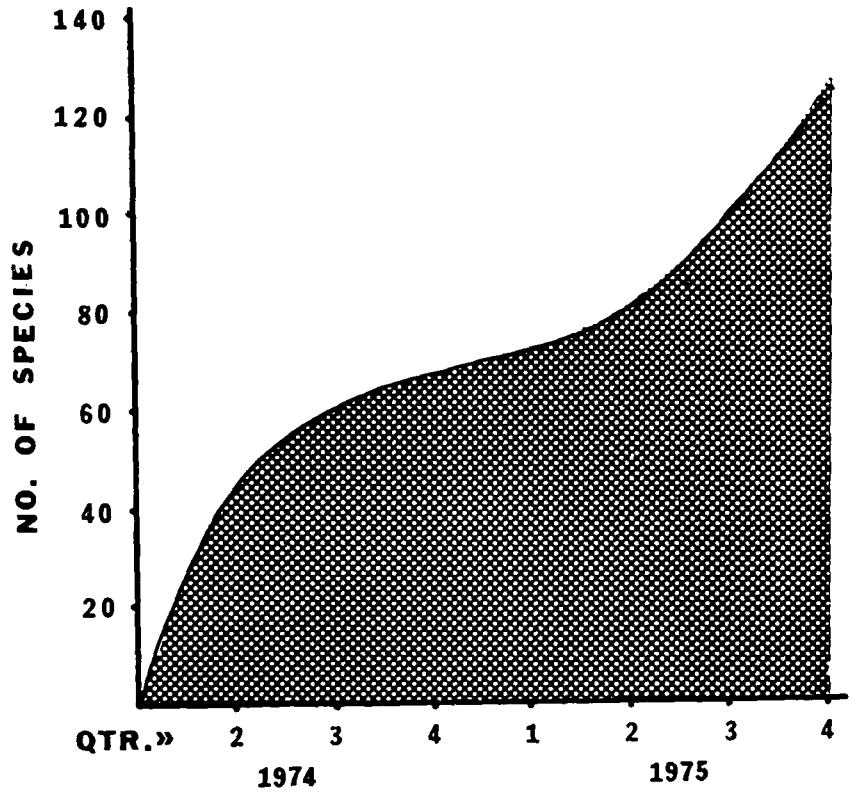

Figure 3. Number of periphyton species identified from the biothermal channels (plotted by quarterly accumulations).

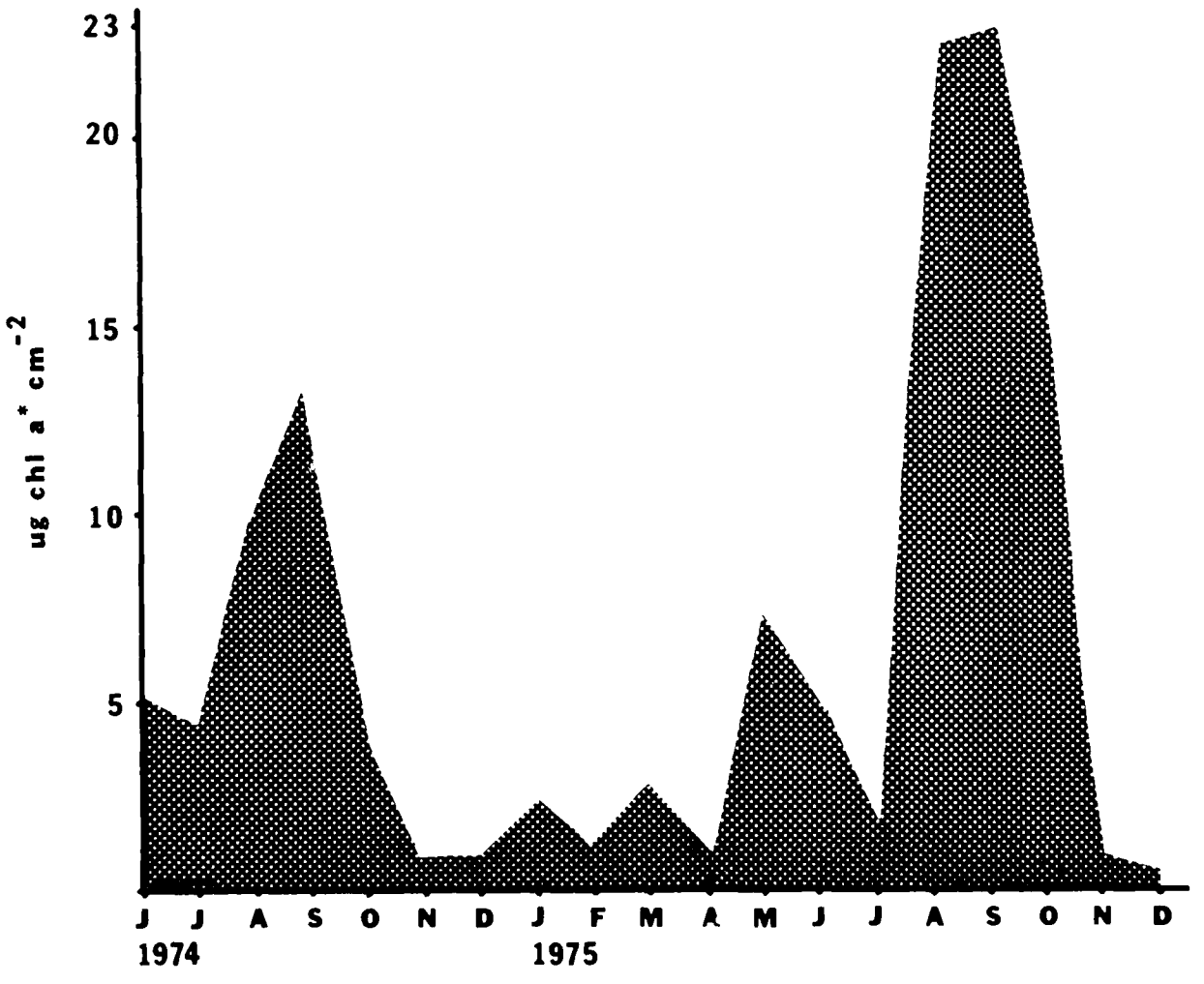

Figure 4. Mean values for active chlorophyll a during the colonization period (15 cm depth).

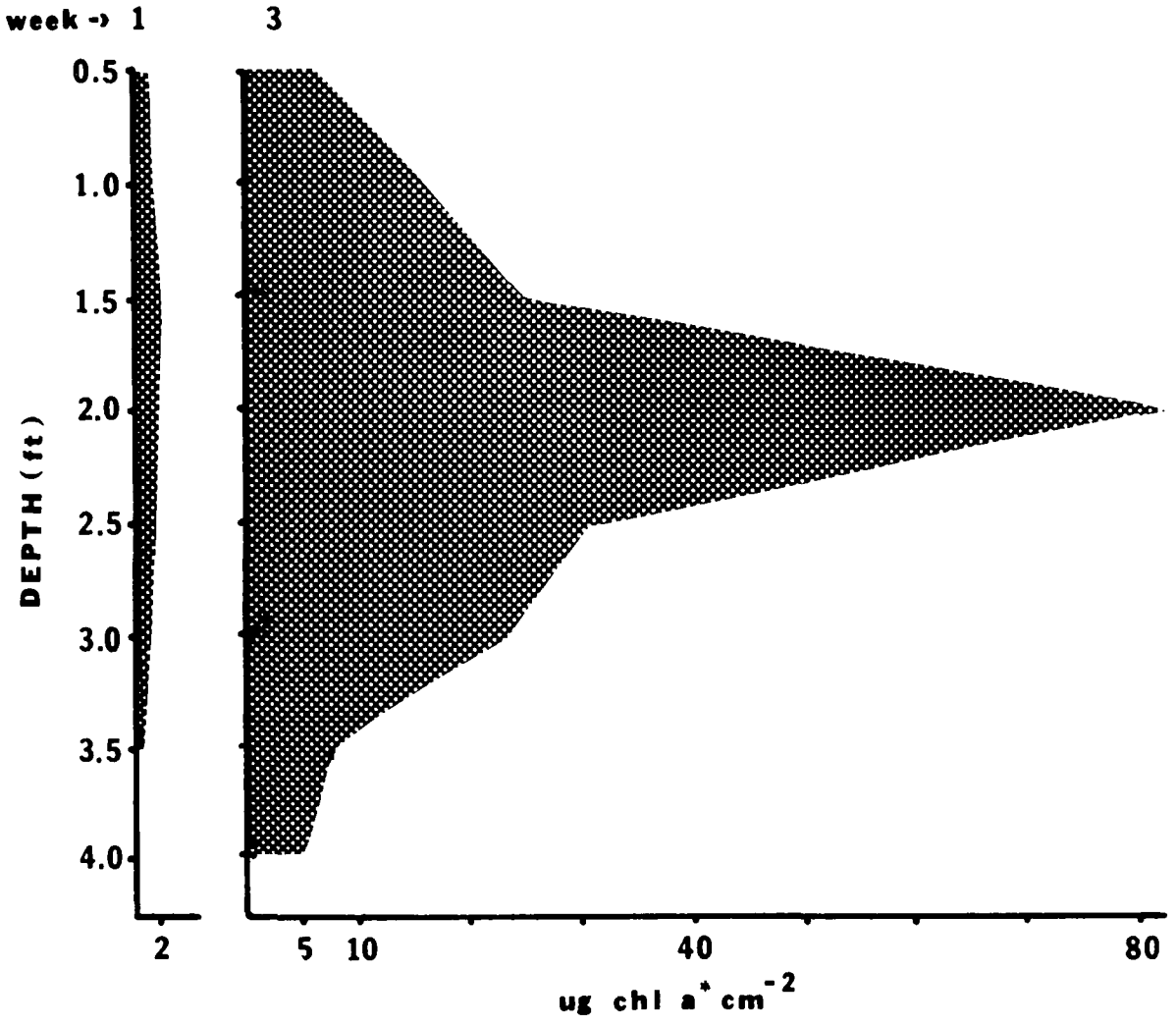

Figure 5. Vertical profiles of active chlorophyll a after 1 and 3 weeks colonization.

SECTION 5

ZOOPLANKTON

SCOPE

Before the biothermal channels were colonized in 1974, the importance of zooplankton in such experimental ecosystems was unknown, since many zooplankton species require open water or cannot tolerate flowing waters (Hutchinson, 1967). The channels were designed to simulate reservoir flows that should not severely limit zooplankton occurrence. Water velocity was adjusted to about 0.14 m/min in pool sections and 0.56 m/min over shallow rock sections. Tennessee River water is pumped continuously to the channels at a rate of 0.66 m^3/min (180 gal/min) and passes through a 2-mm mesh-opening screening system, which allows introduction of most reservoir plankton species.

Because some species of fish to be studied will reproduce in the channels, a well-developed zooplankton community would be desirable to supply natural forage for larval and juvenile stages. The well-known "critical period" for larval fish is successfully transcended only when the right quantity and variety of zooplankton food is present at the initiation of feeding.

The purpose of the zooplankton study was the quantitative assessment of colonization in a channel by analyzing changes in zooplankton abundance and species composition from April through October for two years, 1974 and 1975. Presented here are data for microcrustacean populations only in one channel where there was no fish predation. Planktonic rotiferan populations, although numerous at times, contributed only a small portion to the total zooplankton biomass and were relatively unimportant as food for fish (except as a first food for larvae).

MATERIALS AND METHODS

Zooplankton are known to have patchy distributions in nature, which often makes representative sampling difficult. An additional difficulty is that shallow-water ecosystems often contain many species adapted to benthic habitats. Furthermore, many littoral species are benthic during the day and migrate into the plankton of the more open water during the night (Hutchinson, 1967). To sample a shallow-water ecosystem representatively, investigators must take large-volume samples or many small samples (preferably at night) spaced throughout the study area.

Many small samples provide the more accurate estimation of patchiness, but they are often costly to obtain and analyze. In this study, assessment

of patchiness was not an objective, so composite sampling and large-volume sampling were effectively used to factor out patchiness.

Several types of sampling methods were considered. Plankton traps and water bottles were judged not appropriate for this study because of the large number of samples needed to obtain large composite volumes (>1 m^3) and high numbers of individuals. Use of a plankton pump was considered. Large volumes could be obtained more rapidly and many locations within a channel could be sampled, but the pump would require two operators. The method selected was that of towing a plankton net horizontally by hand along the length of each pool and combining all pool samples. The advantages of the net were that: (a) it sampled volumes of up to 15 m^3, approximately 3% of the total channel volume; (b) it sampled at a constant depth when towed horizontally; (c) it simplified collection of samples by one person; and (d) it collected large amounts of plankton, which made subsampling more convenient and enumeration more accurate than would be possible with small samples.

Samples were collected with a 0.3 m diameter, No. 10 (153 μ mesh) plankton net. Copepod nauplii and small immature ostracods were the only microcrustaceans shown to pass through the No. 10 net. Its efficiency was assumed to be 0.85 (after Cummins, 1969). Estimate of volume filtered, 4.1 m^3, was judged to be precise, since the distance walked in towing could be measured accurately and replicated.

A preliminary test was conducted to assess zooplankton diel periodicity, sampling reproducibility, and enumeration error so that an efficient sampling routine could be determined. A nested experimental design was used over a 24-hour sampling period in December 1974. The nesting consisted of twelve sampling *times* a day (every other hour), at which four *samples* were collected, and of two subsample *enumerations* of each sample. Samples were collected at a constant depth of 0.2 m and distance from the channel wall of 0.5 m. All species showed overwhelming diel periodicity (shown only for the dominant species, *Simocephalus*, in Figure 6). A Nested-ANOVA gave the variance components of 84% due to sampling *time*, 7% due to *sample* replication, and 8% due to *enumeration* error. Only 13% of the *Simocephalus* collected were taken during daylight hours. The zooplankton concentrate near vegetation during the daytime (i.e., attached wall algae, rock areas, and *Chara* in pools) and most species migrate from these daytime habitats at night (unpublished data). Time of day is thus critical to sampling success.

All samples for this study were collected two hours after sunset on the nights of full and quarter moons. Hall, *et al.*, (1970) found it necessary also to sample at night and noted similar diel phenomena in shallow experimental ponds. Zooplankton are more evenly distributed during dark hours so that sampling at night is more efficient and collections are more representative of existing populations than are daytime collections.

Zooplankton counts were converted to biomass using literature values for individual dry weights (Hall, *et al.*, 1970). Although time and equipment did not allow direct dry-weight determinations, biomass estimates were necessary because future studies will relate zooplankton standing crop to

fish feeding patterns. Dry weights for taxa not given by Hall were approximated by size comparison with taxa of known weight. Average weights of cladoceran species were approximated by assuming a one-to-one ratio of adults to juveniles. Adult copepod species (mostly *Mesocyclops edax*) were combined into one category and given an average dry weight of 12 μg. The counts of species within the genera *Ceriodaphnia*, *Daphnia*, and *Simocephalus* were combined by genus for the biomass conversions.

Microcrustacean populations in Wheeler Reservoir were compared with those in the channels through data obtained from the Nuclear Compliance Monitoring Program, Water Quality and Ecology Branch, Division of Environmental Planning, TVA. Samples taken in duplicate on three dates in the reservoir, upstream and downstream from the channel intake water pump in 1974 and 1975, provide the data for these comparisons.

RESULTS

Table 4 lists the species found in the channels through 1975. The dry weights used to convert counts to biomass for dominant species are given. *Leptodora* and *Diaphanasoma* (common in the reservoir) were also present but are not included, as these species occurred only when the channel flows were adjusted nearly to zero. It appears that normal channel flows are sufficient to inhibit these two species. The species present are typical of shallow-water or littoral zooplankton communities. A revised list for 1976 would include several new colonizing species; most notable are *Daphnia ambigua*, *D. catawba*, and *D. parvula*. Also, the abundance of many benthic chydorid species increased in 1976, especially in channels with fish predation.

Figure 7 depicts seasonal changes in total microcrustacean plankton abundance and dry weight biomass for the months sampled in 1974 and 1975. Zooplankton densities were relatively low in 1974 and high in 1975. The decline in zooplankton in 1974 corresponded with the colonization of filamentous algae which reached nuisance proportions by July (see Section 4). In 1975 the algae declined and beds of *Chara* became established in pool areas. It is apparent that dense algal growths drastically prevented zooplankton colonization, since only in the absence of such growths did it proceed. Had growths of filamentous algae continued heavy in 1975, the cause/effect relation between the algae and zooplankton could have been investigated. As it was, algal densities were not high in 1975, and no definitive comment can be made as to cause and effect. Other factors such as anoxia, increased pH, or H_2S toxicity could have been instrumental in causing the observed zooplankton decline, either directly or indirectly, solely, or as a complement to the algal abundance.

Figure 7 also presents abundance data for total microcrustacean plankton collected from the reservoir in the vicinity of the intake which serves as the water source for the channels. In 1974 the abundance was low in the channels compared with that of the reservoir, but it was similar or higher in 1975.

Figure 8 shows water temperature in the channel and abundance data for individual species. The water temperature was taken with a continuous recorder. After May 1974 there were no microcrustacean plankton populations established of any significant density. In 1975 zooplankters of several species were abundant. Ostracods, absent in 1974, colonized in 1975. *Daphnia*, *Ceriodaphnia*, and *Bosmina* showed the most striking increases in abundance in 1975. Copepod densities were similar in the two years. Also depicted in Figure 8 are densities of *Daphnia*, *Bosmina*, and copepods from Wheeler Reservoir. The channel was similar to the reservoir in terms of *Bosmina* and adult copepod populations. The dominant copepod in both ecosystems was *Mesocyclops edax*.

Figure 9 shows the species composition (percent occurrence) in terms of both numbers and biomass for the dominant species given in Figure 7. Data are given for both parameters because biomass alone may overemphasize the importance of large individuals, and numbers alone may overemphasize the importance of small, numerous individuals. In terms of numbers, the small species, *Bosmina*, was overwhelmingly dominant in 1974, but in 1975 no single species dominated numerically. Ostracods became established after being absent in 1974. In terms of percentage biomass, Figure 8 shows that *Simocephalus* dominated alone in 1974. *Daphnia*, *Simocephalus*, and ostracods made up most of the community biomass in 1975. The community composition became more diverse and equable in 1975 compared to 1974.

Table 5 summarizes all the data and presents an overall picture of zooplankton colonization. Shown are yearly average microcrustacean percentage occurrences in terms of numbers and biomass for the channel and numbers only for the reservoir. About 77% of the reservoir microcrustaceans were *Bosmina* followed by copepods at about 20% (for the dates sampled). In the channel in 1974 *Bosmina* (47%) was numerically dominant followed by *Simocephalus* (18%) and *Chydorus* (15%). In 1975 *Bosmina* (29%), *Simocephalus* (5%), and *Chydorus* (10%) all decreased in dominance. Groups becoming more extensively colonized in 1975 were ostracods (22%), *Ceriodaphnia* (13%), *Daphnia* (10%), and copepods (10%). In 1975 five species each represented over 10% of the total community biomass; however, there were only two such species in 1974.

DISCUSSION

The microcrustacean plankton colonizing the channels showed establishment of increased diversity with time. The lack of equability in 1974 is shown in that *Bosmina* dominated numbers and *Simocephalus* dominated biomass. Pioneer ecosystems typically undergo such succession leading to diverse assemblages of biota (Odum, 1973). It is evident that by late 1975, almost two years after colonization began, there was a well-structured zooplankton community in the channel. Although the ecology of individual species has not been discussed in detail here, it can be concluded that the zooplankton community in the channel was represented primarily by shallow-water forms.

The success of the channels in simulating a reservoir ecosystem can be judged in part by the diversity of biota that become colonized. For

zooplankton investigations, the channels offer ecosystems that are relatively easy to study but that are still as complex in species composition as most natural ecosystems. The channels were constructed with distinct areas of silt pools and limestone rocks to offer habitat diversity to colonizing organisms. It has become increasingly evident that spatial heterogeneity in ecosystems correlates directly with species diversity (e.g., MacArthur, 1972). The channels are successful in terms of their potential usefulness for studying zooplankton ecology under controlled seminatural conditions.

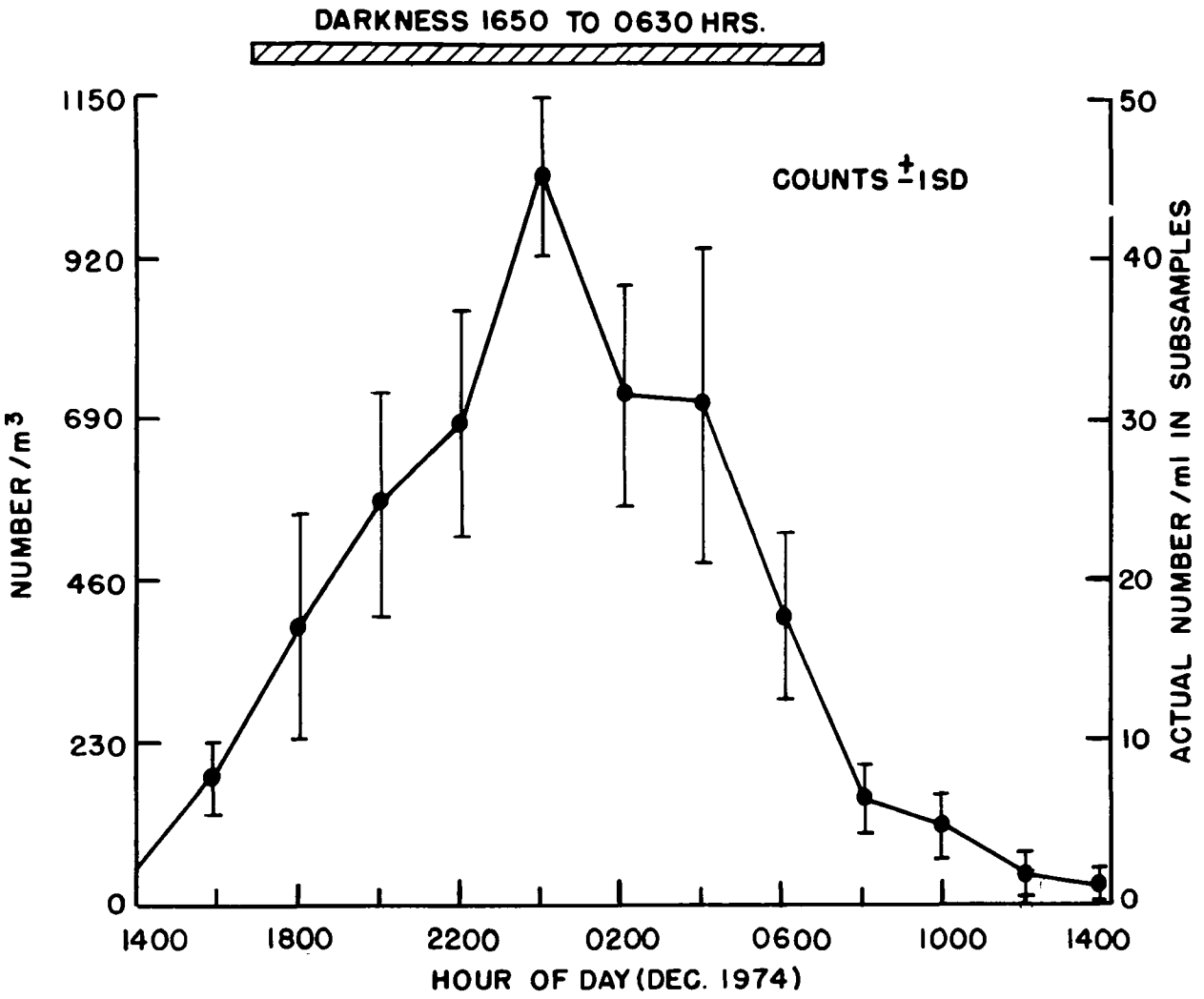

Figure 6. Diel periodicity of *Simocephalus vetulus* (large cladoceran) in a channel during the winter. Diel temperature ranges on the sampling date (December 1974) were 7-15 C air and 5.5-7.5 C water. Four samples were collected every other hour for a 24-hour period by towing a 0.3 m diameter plankton net horizontally the entire length of the channel (112 m) at a constant depth of 0.1 m and a constant distance from the channel wall of 0.5 m.

TABLE 4. MICROCRUSTACEAN PLANKTON FOUND IN CHANNELS AS OF 1975. INDIVIDUAL DRY WEIGHTS IN MICROGRAMS FOR CONVERTING COUNTS TO BIOMASS ARE GIVEN FOR DOMINANT SPECIES

Group	Species	Dry Weight (μg)
Daphnidae		
	Simocephalus vetulus	30.0
	S. serrulatus	30.0
	Daphnia laevis	21.5
	D. pulex	21.5
	Ceriodaphnia reticulata	3.2
	C. quadrangula	3.0
	Moina affinis	
	Scapholeberis kingi	
Sididae		
	Sida crystallina	
	Latona setifera	
Bosminidae		
	Bosmina longirostris	1.4
Macrothricidae		
	Macrothrix rosea	
	Ilyocryptus spinifer	
Chydoridae		
	Chydorus sphaericus	1.5
	C. globosus	
	Disparalona rostrata (Alonella r.)	
	Camptocercus rectirostris (C. similus)	
	Eurycercus lamellatus	
	Kurzia latissima	
	Leydigia quadrangularis (L. leydigi)	
	L. acanthocercoides	
	Pleuroxus denticulatus	
	Alona sp.	
Cyclopoida		12.0
	Mesocyclops edax	
	Cyclops vernalis	
	C. bicuspidatus thomasi	
	Eucyclops agilus	
	E. prionophorus	
	Macrocyclops albidus	
	copepodites	2.0
Calanoida		
	Osphranticum labronectum	18.0
	Diaptomus sp.	
Ostracoda		
	(not identified)	5.0

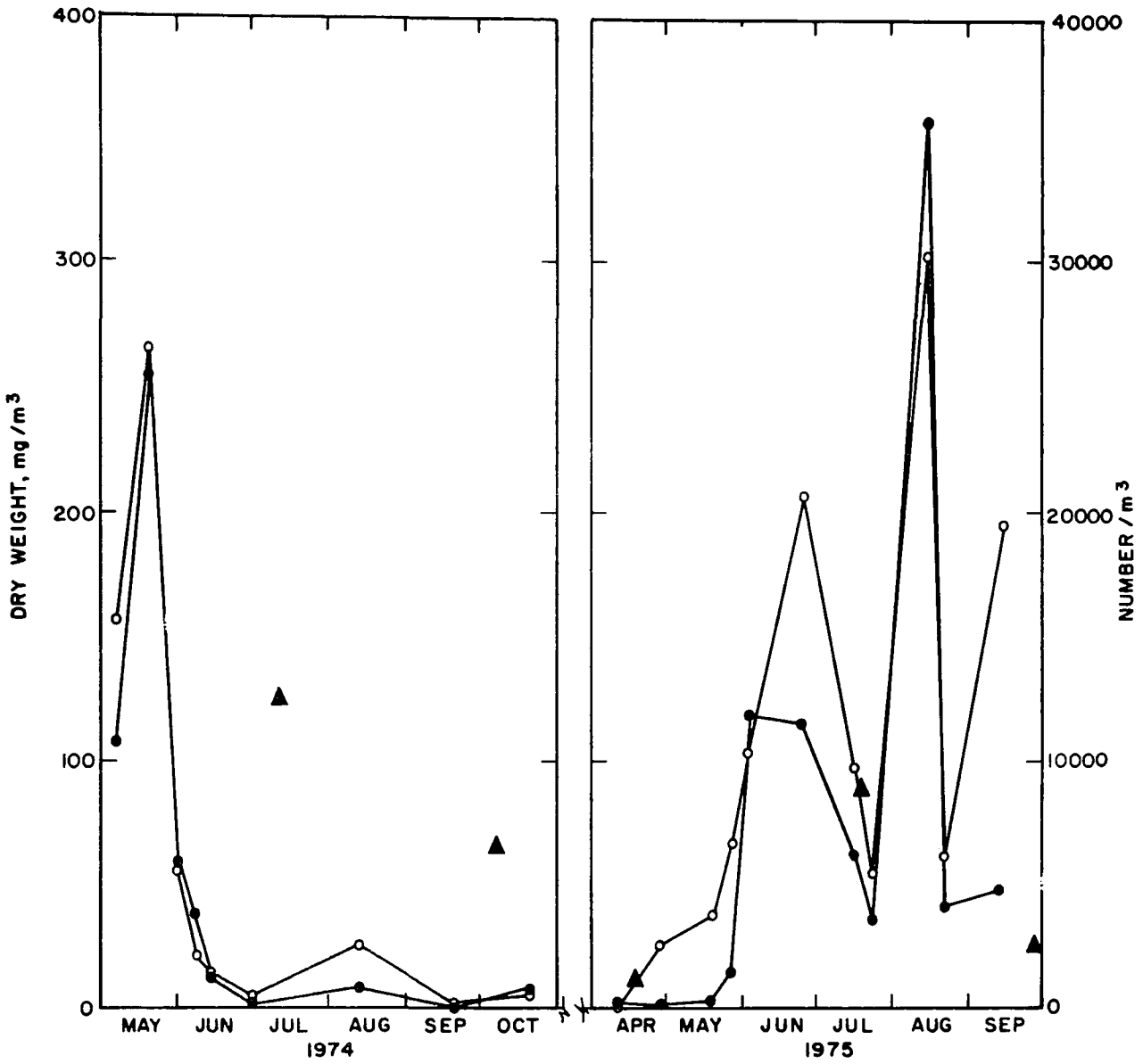

Figure 7. Total microcrustacean plankton density (numbers/m^3) and dry weight biomass (mg/m^3) in a channel for the 1974 and 1975 sampling periods. Densities of Wheeler Reservoir microcrustaceans are given for comparison. Channel density - solid circles; Channel biomass - open circles; and, Reservoir density - solid triangles.

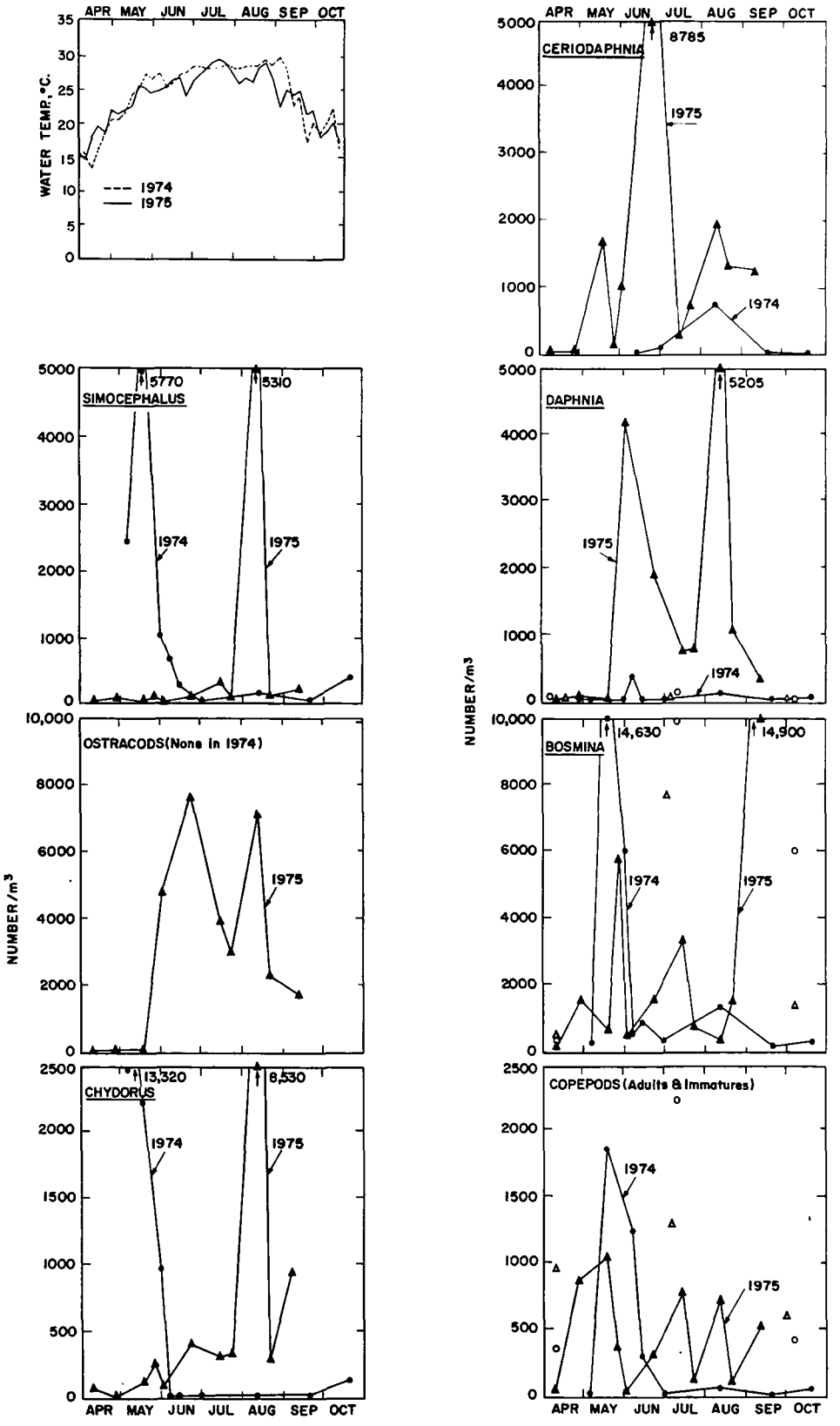

Figure 8. Water temperature and density of the seven dominant taxa in one channel for the 1974 (solid circles) and 1975 (solid triangles) sampling periods. Wheeler Reservoir densities for the three taxa *Daphnia*, *Bosmina*, and copepods (open circles - 1974; open triangles - 1975).

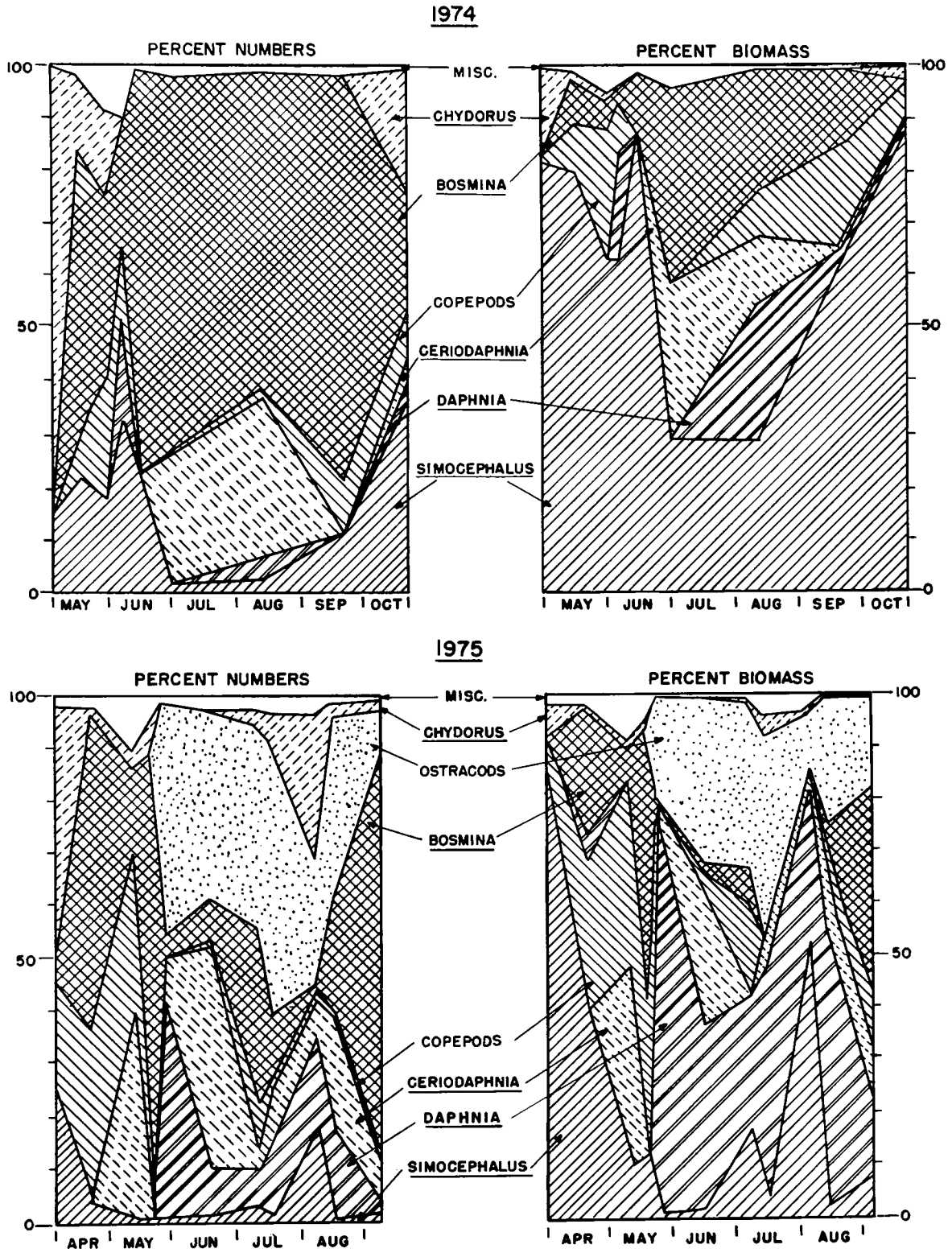

Figure 9. Species composition in terms of percent numbers and percent biomass for 1974 and 1975 sampling periods.

TABLE 5. AVERAGE PERCENT RELATIVE ABUNDANCE IN TERMS OF NUMBERS AND BIOMASS IN ONE CHANNEL AND IN TERMS OF NUMBERS IN WHEELER RESERVOIR. THE AVERAGES ARE FOR MAY THROUGH OCTOBER (NINE DATES) IN 1974 AND APRIL THROUGH SEPTEMBER (ELEVEN DATES) IN 1975. [a]DATA COLLECTED IN APRIL, JULY, AND OCTOBER WERE AVERAGED FOR THE RESERVOIR PERCENT RELATIVE ABUNDANCE

Channel Microcrustacean Zooplankton	Percent Numbers		Percent Biomass	
	1974	1975	1974	1975
Bosmina longirostris	47	29	12	13
Simocephalus vetulus, S. serrulatus	18	5	64	21
Daphnia laevis, D. pulex	3	10	5	25
Ceriodaphnia reticulata, C. quadrangula	7	13	5	9
Chydorus sphaericus	15	10	3	2
Copepods (adults and immatures)	7	10	9	12
Ostracods	-	22	-	16
Others	3	2	2	2
Reservoir Microcrustacean Zooplankton				
Bosmina longirostris	79	75		
Copepods (adults and immatures)	16	23		
Diaphanasoma leuchtenbergianum	3	2		
Leptodora kindtii	1	1		
Daphnia retrocurva, D. parvula	1	1		
Moina minuta	1	1		
Others	1	1		

[a] Data furnished from the Nuclear Compliance Monitoring Program, Water Quality and Ecology Branch, Division of Environmental Planning, TVA.

SECTION 6

MACROINVERTEBRATES

SCOPE

Since summer 1974, studies of macroinvertebrates in the biothermal channels were directed, in large part, toward identifying naturally colonizing species and determining their rates of invasion and subsequent changes in population size. No species were introduced artificially; all were immigrants either by way of Tennessee River water, air, gravid-female adults, or invasion across land. In two cases, organisms were transferred artificially from one channel to another. Crayfish (*Orconectes immunis*), which initially invaded only one channel, were distributed to other channels but did not reproduce, and snails (*Physa heterostropha*) were introduced to one channel which was lacking them.

MATERIALS AND METHODS

All twelve channels were observed and sampled, even though they differed in presence or absence of fish, presence of the same species or numbers of fish, or times at which they were drawn down or refilled. The sampling carried out was indicative, nevertheless, of certain trends or lack of trends.

Three main sampling techniques were employed. These reflect the three main habitat types present in the channels--pool areas, rock areas, and walls. Pools were sampled with a sediment corer made of a piece of PVC pipe of 23.76 cm^2 cross-sectional area. Twelve cores comprised a sample in any one pool on a particular sampling date. Rock areas were sampled with rock-filled galvanized trays of 0.09 m^2 area on which organisms were allowed to colonize for month-long periods. Three trays were placed across each rock area to be sampled. Rocks were scrubbed with a soft brush to remove attached organisms. Invertebrates associated with algal growths on channel walls were sampled with a specially constructed scraping device with an attached net bag; this device sampled an area of 0.25 m^2. Two scrapings were taken from each wall area sampled.

All samples were washed in a No. 70 sieve and were frozen; when thawed, organisms were sorted and counted. A representative subsample of each species present was freeze-dried and weighed.

One experiment was designed specifically to evaluate the recolonization of macroinvertebrates during winter, since this is the period that will be of

particular importance in heated-water experiments. Three channels were drawn down November 5, 1975, leaving approximately 0.5 m of water remaining in pools. The channels were refilled two months later, at which time a six-week sampling program was begun. Three sets of wall scrapings were taken at two-week intervals (January 22, February 4, and February 20, 1976). On each sampling date two scrapings each were taken from the inlet pool, the 44-m pool, and the outlet pool of each of the three channels.

RESULTS

A list of all macroinvertebrates identified during the colonization period is presented in Table 6. Most taxa present in the channels in October 1976 were present at least intermittently during the colonization period (Table 7). Not all organisms present were sampled by the three standard sampling techniques outlined. The invasion of certain taxa was observed by simpler means. Odonates were observed emerging along the channel walls and were subsequently seen laying eggs in the channels. Fifteen anisopteran and one zygopteran species were identified from exuviae and netted adults. These were identified to order in quantitative samples. Five of the anisopteran species were present during the summer of 1974. In both 1975 and 1976, 14 were emergent, 2 species having disappeared while 2 more invaded. The one zygopteran species was present throughout the colonization period.

Isolated *Plumatella* masses were found along the walls in the summers of 1975 and 1976. Two of the bivalve molluscs, *Eliptio crassidens* and *Leptodea fragilis* were not sampled in cores but were found on the sediment near the inlets of drawn-down channels early in 1976. *Orconectes immunis* was found in drawn-down channels in spring 1975. Gravid females distributed to another channel were unsuccessful at reproducing, which may be fortunate in light of evidence of the impact of crayfish feeding and resultant competition with fish in an aquatic system (Magnuson, *et al.*, 1975).

The exuvium from one stonefly (family Perlodidae) was found at the outlet end of one channel in May 1975. This was the only evidence of the presence of Plecoptera in the channels. Certain Hemiptera and Coleoptera were captured only by hand netting. *Belastoma* sp., *Ranatra* sp., and *Mesovilia* sp. were not seen until the summer of 1976. Dytiscidae invaded in 1975. Several of the Trichoptera were found either only at the channel outlets where the current is swift (*Chimarra obscura*, *Cheumatopsyche speciosa*, and *Hydropsyche betteni*), or only as adults on the channel walls (*Athripsodes cancellatus*, *Oecetis inconspicua*, and *Neureclipsis crepuscularis*). These all colonized the channels when they were first filled. All other Trichoptera were sampled as larvae by standard methods. The only Diptera present that were not taken in regular samples were the Simuliidae which inhabit the swift-flowing outlet areas and the Tabanidae which were found in floating algal mats. Both were present beginning in 1974.

Certain genera sampled by the regular techniques were found shortly following initial filling of the channels but were not found subsequently, whereas the reverse was true for other genera. Two coleopterans, *Cercyon* and *Tropisternus*, were collected on rock areas in summer 1974 but not since.

The disappearance of these genera was accompanied by the introduction of others. Gastropod mollusc genera increased from one (*Physa heterostropha*) to five, with the appearance of *Pyrgulopsis* sp. and *Pleurocera canaliculatum* in September 1975 and *Lymnaea* sp. and *Helisoma* sp. in February 1976. All of these were collected in wall scrapings. *Notonecta* sp. was also first seen in wall scraping samples in September 1975. One ephemeropteran, *Baetis bicaudatus* and two trichopterans, *Orthotrichia* sp. and *Oxyethira* sp. appeared in wall scrapings in August 1976. The leech, *Placobdella montifera* appeared in rock trays in late September 1976.

There was great overlap in species collected in all three habitats sampled but certain organisms were found in only one habitat. *Anodonta imbecilis* and *Corbicula manilensis* were found only in pool areas. *Enallagma* sp. and *Libellula* sp. were collected only in rock areas but could probably have been found with more intensive sampling in pools and along the walls. *Tramea onusta* was collected only in wall scrapings but probably inhabited other areas as well. *Notonecta* sp., which was found in wall scrapings, is probably also present in rock areas and is often seen in open water.

Most of the invertebrate populations in the channels reached a peak population density followed by a decline and by subsequent leveling off (Table 8); others showed either upward or downward trends on the final sampling date. For pool areas, this final date was August 21, 1975, so that estimates are not inclusive of the whole colonization period, However, with the exception of the bivalve molluscs and *Hexagenia*, abundance peaks and population trends of all the organisms in pool areas are reflected also in density figures of rock and/or pool areas so that all dates in the table are accurate.

Several organisms showed downward trends in population size at the end of the colonization period: *Erpobdella punctata* and *Helobdella* sp., *Hexagenia bilineata*, *Notonecta* sp., and *Corbicula manilensis*. Organisms showing population size increase were the Amphipoda, Gastropoda, and *Anodonta imbecilis*.

In the recolonization experiment certain organisms showed increased density following channel refilling, while others showed no particular change. Significance of change was shown by use of the Wilcoxon matched-pairs signed-rank test. Amphipoda showed increased densities on both the second and third sampling dates while chironomids and gastropods increased in density between the first and third, and second and third, but not the first and second sampling dates (Table 9). These were the only organisms showing numerical change. There was an increase in the summer biomasses of the invertebrates other than the Gastropoda but these changes were not statistically significant (Table 9).

DISCUSSION

The most abundant organisms to colonize the channels as determined from artificial substrates and core sampling were: Oligochaeta, *Corbicula manilensis* (Pelecypoda), *Erpobdella punctata* (Hirudinea), *Hyalella azteca*

and *Crangonyx* sp. (Amphipoda), *Caenis* sp. (Ephemeroptera), and Chironomidae (Diptera). Odonates and *Hexagenia bilineata* (Ephemeroptera) were also common as determined from exuviae that were collected from the channel walls and water surfaces.

Diversity of macroinvertebrates in the biothermal channels is similar to that in large mainstream reservoirs when both deep water and littoral zones are considered. However, certain organisms dominating reservoir fauna are not dominant in the channels and vice versa. Composition of pool areas in the biothermal channels is similar to that in reservoir open water areas, but with lower densities of *Hexagenia*. Rock and wall areas in the channels show much greater invertebrate diversity than pool areas and are similar to littoral areas in reservoirs in having a greater number of anisopteran odonate species and greater densities of Amphipoda than open-water areas of reservoirs.

TABLE 6. MACROINVERTEBRATE TAXA IDENTIFIED IN BIOTHERMAL CHANNELS DURING COLONIZATION PERIOD

Porifera	
	Spongilla sp.
Hydrazoa	
	Hydra sp.
Ectoprocta	
	Plumatella sp.
Nematoda	
Platyhelminthes	
Turbellaria	
	Dugesia tigrina
Mollusca	
Pelecypoda	
	Anodonta imbecilis *Eliptio crassidens* *Leptodea fragilis* *Corbicula manilensis*
Gastropoda	
Pulmonata	
	Physa heterostropha *Lymnaea* sp.
Planorbidae	
Ctenobranchia	
	Pleurocera canaliculata *Pyrgulopsis letsoni*
Annelida	
Oligochaeta	
Hirudinea	

TABLE 6 (continued)

Helobdella sp.
Erpobdella punctata
Placobdella montifera

Arthropoda

Crustacea

Decapoda

Orconectes immunis

Amphipoda

Hyalella azteca
Crangonyx sp.

Arachnida

Hydracarina

Insecta

Collembola

Ephemeroptera

Heptageniidae

Stenonema sp.

Ephemeridae

Hexagenia bilineata

Baetidae

Baetis bicaudatus
Callibaetis fluctuans
Caenis sp.

Odonata

Anisoptera

Gomphidae

Dromogomphus spoliatus

TABLE 6 (continued)

Libellulidae

Epicordulia princeps
Epicordulia regina
Pachydiplax longipennis
Erythemis simplicicollis
Libellula pulchella
Libellula luctuosa
Libellula forensis
Plathemis lydia
Perithemis tenera
Pantala hymenea
Pantala flavescens
Tramea onusta
Macromia taeniolata
Macromia illinoiensis

Zygoptera

Coenagrionidae

Enallagma civile

Plecoptera

Perlodidae

Hemiptera

Belastomatidae

Belastoma sp.

Nepidae

Ranatra sp.

Notonectidae

Notonecta sp.

Mesoveliidae

Mesovelia sp.

Trichoptera

Philopotamidae

TABLE 6 (continued)

Chimarra obscura

Psychomyiidae

Cyrnellus fraternus
Neureclipsis crepuscularis

Hydropsychidae

Cheumatopsyche speciosa
Hydropsyche betteni

Hydroptilidae

Hydroptila waubesiana
Orthotrichia sp.
Oxyethira sp.

Leptoceridae

Athripsodes cancellatus
Oecetis inconspicua

Coleoptera

Hydrophilidae

Cercyon sp.
Berosus sp.
Tropisternus sp.

Dytiscidae

Diptera

Simuliidae

Chironomidae

Chironominae

Glyptotendipes sp.
Dicrotendipes fumidus
Dicrotendipes modestus
Paratanytarsus sp.

Orthocladiinae

TABLE 6 (continued)

Cricotopus (Isocladius) Sylvestris group
Pseudosmittia sp.

Tanypodinae

Tanypus (Apelopia) neopunctipennis

Ceratopogonidae

Probezzia sp.

Tabanidae

Chrysops sp.

Blephariceridae

TABLE 7. MACROINVERTEBRATE TAXA OBSERVED IN THREE SAMPLE AREAS ON SUCCEEDING DATES

	Rocks								Pools								Walls				
	7/74	10/74	4/75	6/75	7/75	8/75	9/75	2/76	7/74	12/74	1/75	2/75	5/75	6/75	7/75	8/75	9/75	1/76	2/76	4/76	5/76
Dugesia sp.	*	*	*		*	*	*		*						*		*		*		*
Spongilla sp.																					
Hydra sp.																			*	*	
Nematoda								*	*	*	*	*			*				*	*	*
Oligochaeta	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*		*
Erpobdella punctata			*	*	*	*	*	*	*	*	*	*	*	*	*	*			*	*	*
Helobdella sp.	*	*	*	*	*	*	*						*		*	*	*				*
Hydracarina																			*	*	*
Amphipoda†	*	*	*	*	*	*	*	*		*							*	*	*		
Crangonyx sp.																				*	*
Hyalella azteca													*	*	*	*				*	*
Collembola																		*		*	
Hexagenia bilineata		*			*	*	*		*			*	*								
Stenonema sp.	*	*							*								*	*	*		*
Caenis sp.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Callibaetis fluctuans	*	*				*	*	*												*	
Epicordulia sp.		*					*								*				*		*

TABLE 7 (continued)

	Rocks								Pools								Walls				
	7/74	10/74	4/75	6/75	7/75	8/75	9/75	2/76	7/74	12/74	1/75	2/75	5/75	6/75	7/75	8/75	9/75	1/76	2/76	4/76	5/76
Erythemis simplicicollis	*		*	*	*	*									*						
Pantala sp.	*	*			*	*	*		*								*				
Plathemis lydia																			*		
Tramea onusta	*																*				
Enallagma civile	*	*	*			*	*	*											*	*	
Corixidae	*		*	*	*	*	*	*	*						*	*		*	*	*	*
Notonecta sp.							*	*									*		*		
Berosus sp.	*				*				*			*				*					*
Cercyon sp.	*																				
Tropisternus sp.	*																				
Hydroptila waubesiana	*	*	*		*	*					*		*		*				*	*	
Athripsodes cancellatus		*																			
Cyrnellus fraternus	*	*				*	*		*								*				
Probezzia sp.	*	*	*	*	*	*				*	*	*	*	*	*	*					*
Chironomidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Chrysops sp.	*																				

TABLE 7 (continued)

	Rocks								Pools								Walls				
	7/74	10/74	4/75	6/75	7/75	8/75	9/75	2/76	7/74	12/74	1/75	2/75	5/75	6/75	7/75	8/75	9/75	1/76	2/76	4/76	5/76
Belephariceridae																					*
Gastropoda†	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Lymnaea sp.																				*	*
Physa heterostropha																	*	*	*	*	*
Pyrgulopsis letsoni																	*		*	*	*
Pleurocera canaliculata																					
Helisoma																			*		
Pelecypoda†		*																			
Anodonta imbecilis													*	*	*	*					
Corbicula manilensis									*	*	*	*	*	*	*	*					

† Taxon used before genera were identified.

TABLE 8. POPULATION TRENDS OF TAXA SAMPLED IN CHANNELS BETWEEN SUMMER, 1974 AND SPRING, 1976

	Date of Peak Abundance	Habitat	Estimated No./m^2 at Peak[a]	Direction of Population Density Change[b]	Approximate Stable Population Density (No./m^2) Spring 1976
Dugesia sp.	10/74	rocks	603	↳	∿20
Nematoda	1/75	pools	420	↳	∿10
Oligochaeta	1/75	pools	10,276	↳	∿100
Erpobdella punctata	7/75	pools	1,192	↓	
Helobdella sp.	7/75	pools	193	↓	
Amphipoda	2/76	rocks	3,194	↑	
Hexagenia bilineata	2/75	pools	35	↓	
Stenonema sp.	10/74	rocks	9	→	∿5
Caenis sp.	12/74	pools	3,753	↳	∿50
Callibaetis fluctuans	9/75	walls	45	↳	∿5
Anisoptera	10/74	rocks	24	↳	∿10
Enallagma civile	10/74	rocks	14	↳	∿5
Corixidae	7/75	rocks	241	↳	∿2
Notonecta sp.	9/75	walls	9	↓	
Berosus sp.	2/75	pools	35	↳	∿2
Hydroptila waubesiana	10/74	rocks	340	↳	∿5

TABLE 8 (continued)

	Date of Peak Abundance	Habitat	Estimated No./m^2 at Peak[a]	Direction of Population Density Change[b]	Approximate Stable Population Density (No./m^2) Spring 1976
Cyrnellus fraternus	8/75	rocks	63	↓	
Probezzia sp.	12/74	pools	420	↳	∿20
Chironomidae	5/76	walls	1,001	↑	
Gastropoda	5/76	walls	532	↑	
Anodonta imbecilis	8/75	pools	113	↑	
Corbicula manilensis	7/75	pools	6,039	↓	

[a] Mean of all samples taken in a particular habitat on one date.

[b] Explanation of symbols.

↑ = Increase

↓ = Decline

↳ = Decline and leveling off

TABLE 9. NUMBERS AND DRY WEIGHTS (mg) OF ORGANISMS PER m^2 ON WALL AREAS ON SUCCESSIVE SAMPLING DATES IN 1976. (1: JANUARY 22, 2: FEBRUARY 4, 3: FEBRUARY 20). DATA REPRESENT TWO SAMPLES PER WALL AREA, AVERAGED AMONG THREE CHANNELS

a) Mean numbers per m^2

AMPHIPODA

Wall Area	Sampling Date 1	2	3
1	24	344	888
1	36	468	1016
3	184	284	592
3	76	184	316
6	16	48	140
6	16	96	152

1-2*
2-3*
1-3*

CHIRONOMIDAE

Wall Area	Sampling Date 1	2	3
1	92	160	1180
1	236	169	1036
3	363	535	1388
3	371	701	2120
6	245	400	728
6	115	256	956

1-2 ns
1-3*
2-3*

GASTROPODA

Wall Area	Sampling Date 1	2	3
1	11	56	1180
1	26	56	1036
3	28	61	1388
3	37	45	2120
6	39	69	728
6	35	25	940

1-2 ns
1-3*
2-3*

b) Dry weight (mg) per m^2

POOLED INVERTEBRATES MINUS GASTROPODA

Wall Area	Sampling Date 2	3
1	1235	1802
1	385	4496
3	1060	4427
3	1314	6254
6	3510	3490
6	4429	5044

ns

GASTROPODA

Wall Area	Sampling Date 2	3
1	11345	7845
1	13228	10936
3	2378	10010
3	5222	6476
6	9474	6427
6	2690	3661

ns

* Significant difference at 95 percent level (Wilcoxon's rank test, Siegel, 1956)

ns - Non significant

REFERENCES

Biswar, S. 1969. The Volta Lake: Some ecological observations on the phytoplankton. Verh. Int. Ver. Limnol. 17: 259-272.

Cummins, K. W., R. R. Costa, R. E. Rowe, G. A. Moshiri, R. M. Scanlon, and R. K. Zajdel. 1969. Ecological energetics of a natural population of the predaceons zooplankter *Leptodora kindtii* Fock (Cladocera). Oikos 20: 189-223.

Funk, W. H., and A. R. Gaufin. 1971. Phytoplankton productivity in a Wyoming cooling-water reservoir. Pages 167-178 *In* G. E. Hall, ed. Reservoir fisheries and limnology. Spec. Publ. No. 8. Amer. Fish. Soc., Washington.

Hall, D. J., W. E. Cooper, and E. E. Werner. 1970. An experimental approach to the production dynamics and structure of freshwater animal communities. Limnol. Oceanogr. 15(6): 839-928.

Hutchinson, G. E. 1967. A treatise on limnology. Vol. II. Introduction to lake biology and limnoplankton. John Wiley & Sons, Inc., New York. 1115 pp.

Hutchinson, G. E. 1975. A treatise on limnology. Vol. III. Limnological botany. John Wiley & Sons, Inc., New York. 660 pp.

Leentvaar, P. 1966. The Brokopondo Lake in Surinam. Verh. Int. Ver. Limnol. 16: 680-684.

MacArthur, R. H. 1972. Geographical ecology. Harper and Row, New York. 269 pp.

Magnuson, John J., Gregory M. Capelli, James G. Lorman, and Roy A. Stein. 1975. Consideration of crayfish for macrophyte control. Rept. No. ENV 07-75-1 Univ. of Florida, Gainesville.

Odum, E. P. 1971. Fundamentals of ecology (3rd ed.). W. B. Saunders Co., Philadelphia. 574 pp.

Rodhe, W. 1964. Effects of impoundment on water chemistry and plankton in Lake Ransaren (Swedish Lappland). Verh. Int. Ver. Limnol. 15: 437-443.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Co., Philadelphia. 743 pp.

Zhadin, V. I., and S. V. Gerd. 1961. Fauna and flora of the rivers, lakes, and reservoirs of the U.S.S.R. Keter Press, Jerusalem.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/3-78-020	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Browns Ferry Biothermal Research Series I. Colonization by Periphyton, Zooplankton, and Macroinvertebrates		5. REPORT DATE February 1978 issuing date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Brian J. Armitage, Thomas D. Forsythe, Elizabeth B. Rodgers, and William B. Wrenn		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Tennessee Valley Authority FF&WD - Biothermal Research Facility P.O. Box 2000 Decatur, Alabama 35602		10. PROGRAM ELEMENT NO. 1BA608
		11. CONTRACT/GRANT NO. TV-35013A
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Research Laboratory--Duluth, MN Office of Research and Development U.S. Environmental Protection Agency Duluth, Minnesota 55804		13. TYPE OF REPORT AND PERIOD COVERED Interim
		14. SPONSORING AGENCY CODE EPA/ 600/03

15. SUPPLEMENTARY NOTES
Research performed in cooperation with Tennessee Valley Authority, Norris, Tennessee 37828

16. ABSTRACT

Colonization studies on a series of 12 outdoor experimental channels supplied with water from Wheeler Reservoir (Tennessee River) were completed at the Browns Ferry Biothermal Research Station in Alabama. Species composition, dominance, seasonal patterns, colonization rates, and biomass estimates were determined over a 24-month period for periphyton, zooplankton, and macroinvertebrates. In general, the species composition and the relative densities of algal and invertebrate organisms that colonized the channels indicated that the channels successfully simulate reservoir ecosystems for those trophic levels.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Zooplankton	Colonization Experimental channels Periphyton Macroinvertebrates	50 B 68 D

18. DISTRIBUTION STATEMENT Release to public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 54
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

INSTRUCTIONS

1. **REPORT NUMBER**
Insert the EPA report number as it appears on the cover of the publication.

2. **LEAVE BLANK**

3. **RECIPIENTS ACCESSION NUMBER**
Reserved for use by each report recipient.

4. **TITLE AND SUBTITLE**
Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.

5. **REPORT DATE**
Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected *(e.g., date of issue, date of approval, date of preparation, etc.)*.

6. **PERFORMING ORGANIZATION CODE**
Leave blank.

7. **AUTHOR(S)**
Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.)*. List author's affiliation if it differs from the performing organization.

8. **PERFORMING ORGANIZATION REPORT NUMBER**
Insert if performing organization wishes to assign this number.

9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hirearchy.

10. **PROGRAM ELEMENT NUMBER**
Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.

11. **CONTRACT/GRANT NUMBER**
Insert contract or grant number under which report was prepared.

12. **SPONSORING AGENCY NAME AND ADDRESS**
Include ZIP code.

13. **TYPE OF REPORT AND PERIOD COVERED**
Indicate interim final, etc., and if applicable, dates covered.

14. **SPONSORING AGENCY CODE**
Leave blank.

15. **SUPPLEMENTARY NOTES**
Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.

16. **ABSTRACT**
Include a brief *(200 words or less)* factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **KEY WORDS AND DOCUMENT ANALYSIS**
(a) DESCRIPTORS - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

(b) IDENTIFIERS AND OPEN-ENDED TERMS - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

(c) COSATI FIELD GROUP - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field/Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **DISTRIBUTION STATEMENT**
Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.

19. & 20. **SECURITY CLASSIFICATION**
DO NOT submit classified reports to the National Technical Information service.

21. **NUMBER OF PAGES**
Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.

22. **PRICE**
Insert the price set by the National Technical Information Service or the Government Printing Office, if known.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978—[illegible]