The thickness determinations for x-ray measurements were based on equation (2). The photoelectric cross section σ was ascertained (Siegbahn, 1965) and the intensities before and after the foil were obtained by extracting the area under the x-ray peak in a pulse height spectrum. The area extraction was accomplished by a computer routine which fit a Gaussian curve to the peak and a second degree polynomial to the background on either side of the peak. The integrated area under the Gaussian curve in the region of interest less that under the background curve was taken as the intensity of the x-ray beam. The results are presented in Table 2 together with a comparison of the results in Table 1. In making the comparison it will be noted that two or more of the foils used in making the alpha measurements were combined to serve as a single foil for the x-ray measurements.

From equation (2) it can be seen that a graph of the foil thickness (obtained from alpha energy loss measurements) vs. $\ln(I/I_0)$ will yield the photoelectric cross section σ. The result of a linear least-squares fit to such a graph gives a result (80.6 cm^2/gm) which compares favorably with theory (4%). This uncertainty is comparable to that associated with the alpha energy-loss measurements.

Alpha particle energy loss and x-ray absorption studies can be useful in determining foil thickness or foil uniformity. The primary advantage offered by the former method lies in the data reduction. This is due to the fact that one need know only the position of the alpha peak in the pulse height spectrum, whereas in the x-ray method the area must be computed. The x-ray method has the advantage that the procedure may be performed in air with negligible error, whereas the other technique requires an evacuated system. Due to the exponential absorption of x-rays, one is not limited to thin foils as is the case for alpha studies. The accuracy of the method, in either case, will be limited by the uncertainties for either dE/dx or σ.

TABLE 1. *Cu foil thickness determined by alpha energy loss measurements*

Foil Number	Energy (MeV)	Thickness (mg/cm^2)
	5.48	0.00
0	4.19	3.01
1	4.20	3.00
2	4.16	3.10
3	4.72	1.84
4	4.92	1.32
5	4.37	2.63
6	3.13	5.18
7	4.53	2.30
8		

TABLE 2. *Cu foil thickness determined by x-ray absorption measurements together with a comparison to alpha results*

$I_0 = 15840$; $\sigma = 84$ gm/cm^2.

Foil Number	Y	Thickness (mg/cm^2)	Uncertainty (%)
1-2	9580	5.99	0.3
1-3	8050	8.07	11.4
1-5	6095	11.32	7.7
1-8	2585	21.58	3.6

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THE CLADOCERA AND COPEPODA OF TENNESSEE II. CYCLOPOID COPEPODS

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ABSTRACT

An eight-year survey was conducted in Tennessee to determine the distribution and habitat preference of cyclopoid copepod species. Twenty two species in eight genera were recorded from the state, of which eight were reported for the first time. Nine species were collected from more than two habitats, three were collected only in caves, seven were found in small streams, springs, and/or pools, and three were collected only in rivers and associated reservoirs. Seven species were listed as expected to occur in Tennessee in future collections. The names *Cyclops bicuspidatus thomasi* and *Cyclops varicans rubellus* were rejected in favor of *Cyclops thomasi* and *Cyclops rubellus*.

INTRODUCTION

The cyclopoid copepods of the southeastern states are not well known. Published studies are restricted to areas of some biological interest such as Reelfoot Lake, and to regions surrounding academic institutions containing individuals interested in the Crustacea. These localized studies have resulted in distributional data that are very incomplete and as Coker (1938) noted, even quite erroneous. The purpose of this paper, then, is to summarize and extend our present knowledge of the species composition and distribution of cyclopoids within Tennessee.

A literature review revealed reports concerning copepods from Reelfoot Lake (Eddy, 1930; Hoff, 1944), the Elk River and Woods Reservoir (Yeatman, 1956), and a few sinks, ponds, and lakes in the Knoxville area (Green, 1933, 1934). In addition to these studies, unpublished records were provided by the Tennessee Valley Authority and Dr. Harry C. Yeatman.

METHODS

This report includes 653 samples taken from 476 localities over an eight year period. Most collecting was done in middle and eastern Tennessee; moderate effort was directed to western portions of the state. Collections were made with no. 20 and no. 3 plankton townets in lakes and ponds, and dip nets were used in pools and along the edges of streams. Seasonal data were provided by sampling during most months of the year and visiting many localities on several different dates. Identifications were confirmed using Yeatman (1944, 1959), Rylov (1948) and Dussart (1969).

ANNOTATED LIST OF SPECIES

Genus *Cyclops* O. F. Müller

Cyclops carolinianus (Yeatman). Yeatman (1944) described this species from individuals taken from pools in the vicinity of Chapel Hill, N. C. He considered the only definite structural difference between this species and a close relative, *C. vernalis*, to be the presence of small hairs on the inner margins of the caudal rami of the former. In Tennessee we have collected specimens in six temporary pools in Jefferson, Hamilton, and Blount Counties; these specimens differ from the types in the variable nature of the hairs. A detailed discussion of variability encountered in this and other cyclopoid species is in preparation.

Cyclops clandestinus (Yeatman). Yeatman (1964) described this species from specimens obtained in Bigmouth Cave, Grundy County, Tennessee and from a drainage tile emptying into Jordan Creek, Vermillion County, Illinois. To date, the Bigmouth Cave collection is apparently the only record from the state. The species is considered a troglophile and it has never been collected epigean waters.

Cyclops crassicaudis brachycercus (Kiefer). Considered as uncommon in North America, this species inhabits stagnant, temporary pools and wells (Yeatman, 1959) and littoral areas of shallow lakes (Rylov, 1948). Specimens taken from a shallow, stagnant pool in Wilson County constitute the only record in the present study. Since Yeatman did not include Tennessee in the distribution of the species, this represents the first published record for the state.

Cyclops donnaldsoni (Chappuis). Yeatman (1959) indicated the distribution of this species to be limited to a cave in Indiana, however, he has since identified specimens from a small cave in McMinn County, Tennessee (personal communication).

Cyclops evilis (Coker). In March and April, 1969, I identified a few specimens of this species from two springs in Knox County. Other localities given by Yeatman (1959) are North Carolina and New York. Very little is known concerning this copepod, and, as far as I can determine, only the previous distribution records are available. A study of the life history and morphology is presently being undertaken.

Cyclops haueri (Kiefer). *Cyclops haueri* was considered by Yeatman (1959) to be rare in North America, recorded only from Connecticut and Ohio. The species is evidently confined to temporary pools in Winter and Spring. I have identified it from 27 such habitats in Knox, Putnam, Jefferson, and Overton Counties; in many samples it was the most abundant crustacean present. I have also examined samples containing the species from two temporary pools in northern Alabama.

Cyclops latipes (Lowndes). Yeatman (personal communication) has collected this species in several small, intermittent streams in Franklin County. I have recorded it from a slowly flowing, temporary pool in Hamilton County. Yeatman (1959) listed the North American distribution as North Carolina, Michigan, and Tennessee. Though little is known concerning the biology of this species, it evidently prefers cold, shallow bodies of water with some intermittent flow.

Cyclops thomasi (S. A. Forbes). During colder months, this limnetic species is the major planktonic cyclopoid in the reservoirs of the TVA system. It has apparently never been collected in small shallow pools in the southeastern United States.

Cyclops thomasi has been considered by most authors to be a subspecies of *C. biscuspidatus;* I prefer to follow Reed (1963) in considering it a separate species. In addition to Reed's characteristics for separating the species, I have noted significant variation in the presence of small hairs on the inner margins of the caudal rami. Hairs are absent in *C. biscuspidatus* from other parts of the world. All authors, except Marsh (1910), have described *thomasi* without hairs. A discussion of variation in this species is in preparation.

Cyclops rubellus (Lilljeborg). *Cyclops rubellus* has usually been considered a subspecies of *C. varicans*. The principal morphological differences between the two (see Yeatman, 1944 and Rylov, 1948) appear to be sufficient to accord *rubellus* specific status (Kiefer, 1929; Reed, 1963; Dussart, 1969).

A typical inhabitant of macrophyte vegetation in shallow waters of ponds and pools, little is known about the biology of the species. The writer has collected specimens in eight such habitats in the eastern part of Tennessee from January through April. Rylov (1948) considered it a bicyclic summer form found typically in acid waters.

Hoff's record of *C. bicolor* from Reelfoot Lake was probably this species. Yeatman (1944) indicated that most American records for *bicolor* were *varicans rubellus*.

Cyclops venustoides Coker. This copepod has been reported from North Carolina, Ohio, and Alaska by Yeatman (1959), from Ontario and the Northwest Territories by Reed (1963), and from Illinois by Yeatman

(1964). A subspecies, *C. v. bispinosus* Yeatman, has been collected in Ohio and Quebec. Most records are from small bodies of water, however, the Illinois specimens were obtained from hypogean water in association with *C. clandestinus*.

Tennessee specimens were collected during January and February in a flooded area in Elsie Chapin Wildlife Sanctuary, Hamilton County. A weak current was detectable with overflow to South Chickamauga Creek. This species apparently prefers temporary habitats during times of low temperature.

Cyclops vernalis Fischer. *Cyclops vernalis*, a cosmopolitan and very variable species, occurs through most of the year in virtually all aquatic habitats. In Tennessee it appears to reach maximum abundance during the Fall, Winter, and Spring; in some habitats it may reach a second peak during the Summer. Most collections of this species are from temporary pools and ponds. I have also identified it with some regularity in plankton tows from Cherokee, Santeetlah, Ft. Loudoun, Kentucky, and Douglas Reservoirs. Most investigators consider *vernalis* a littoral form; its presence in the plankton of reservoirs may be only accidental. Rylov (1948)stated that this species should not be considered pelagic.

Present state records include Reelfoot Lake (reported as *C. viridis*) by Eddy (1930) and Hoff (1944), Andrew Jackson Lake and surrounding areas (reported as *C. virdis americanus*) by Green (1934), and Woods Reservoir by Yeatman (1956).

Genus *Ectocyclops* Brady

Ectocyclops phaleratus (Koch). Green (1933) recorded this species from a small artificial pond near Knoxville and from a muddy rain pool near Andrew Jackson Lake. Its distribution is worldwide (Dussart, 1969). In North America it is uncommon but found over most of the United States and southern Canada (Yeatman, 1959). A typical inhabitant of littoral zones in lakes and permanent shallow ponds, this form is rarely found in springs (Rylov, 1948). Most records indicate a eurythermal occurrence with some preference for warmer waters.

Genus *Eucyclops* Claus

Eucyclops agilis (Koch). *Eucyclops agilis* is evidently one of the most common and widely distributed littoral copepods known (Comita, 1951; Yeatman, 1959). A eurythermal inhabitant of a wide variety of epigean and hypogean environments, this species avoids open water with a strong current (Rylov, 1948). In Tennessee it has been collected in a cave (Yeatman, 1964); in sinks, small lakes, and springs (Green, 1933); and in Reelfoot Lake (Hoff, 1944). I have identified it from 93 localities which include springs, temporary pools, lakes, ponds, reservoirs, and crayfish burrows.

Eucyclops priorophorus (Kiefer). Tennessee specimens are noted from the Elk River in Franklin County (Yeatman, personal communication), from Woods and Ft. Loudoun Reservoirs, from a sink on the bank of Norris Reservoir, and by TVA investigators from Barkley, Nickajak, Sequoyah, and Watts Bar Reservoirs. Little is known concerning the biology and ecology of this rarely seen species. Yeatman (1959) gave the distribution as Connecticut, North Carolina, and Tennessee.

Eucyclops speratus (Lilljeborg). We have collected this species from a number of permanent and temporary ponds from December through April in most of eastern Tennessee. Only one site, in Knox County, contained it during the summer months. Yeatman (personal communication) collected it in the Elk River prior to the impoundment of Woods Reservoir, and Green (1934) listed *Cyclops serrulatus elegans* from sinks in Knox County. It is probable that Green was dealing with *E. speratus*. Though not very common, the species appears to be widely distributed and may have a preference for shallow, cold water in Tennessee. Dussart (1969) described it as eurythermal in European waters.

Genus *Macrocyclops* Claus

Macrocyclops albidus (Jurine). Yeatman (1959) described this as one of the most common of North American copepods. Found in most aquatic habitats, *M. albidus* prefers shallow water. Rylov (1948) indicated that this species was eurythermal and polycyclic, with three sexual cycles a year in the U.S.S.R. Green (1933), Hoff (1944), and Yeatman (1956) have recorded the species from Tennessee, and it has appeared in 55 of my collections from a variety of habitats.

Macrocyclops fuscus (Jurine). A common and widespread species, *M. fuscus* may be encountered during any time of the year. Green (1933) collected one specimen from Andrew Jackson Lake in November. This is apparently the only published account of the species in Tennessee. I identified it from five localities in East Tennessee, all of which were cold, slow-moving streams. All specimens were taken from vegetation along the sides of the streams where the current was quite slow.

Genus *Mesocyclops* Sars

Mesocyclops edax (S. A. Forbes). Probably the most common limnetic copepod in the United States and southern Canada, this species occurred in 73 of my samples from the state. It was collected during most of the year in permanent ponds, lakes, and reservoirs. Yeatman (1956) records this species from Woods Reservoir, Arrow Lake near Mt. Pleasant, and in Mt. Lake near Tracy City. Green (1934) listed *Cyclops leuckarti* from Andrew Jackson Lake, though he was probably dealing with *M. edax*. All records for *leuckarti* and *edax* prior to Coker (1943) need to be examined as there was much confusion regarding the distinction between these species.

Mesocyclops leuckarti (Claus). Evidently *M. leuckarti* is rare in North America, although widely distributed. Most records indicate that it is a limnetic species that prefers warm water. In Europe it is quite common and lives in a wide variety of habitats ranging from pools to large lakes.

Yeatman (1956) collected *M. leuckarti* in the Elk River prior to and following impoundment of Woods Reservoir. Recent samples from this locality contained only *M. edax* and intensive sampling during summer months will be required to clarify its status.

Genus *Orthocyclops* E. B. Forbes

Orthocyclops modestus (Herrick). The single species in the genus, *O. modestus*, is apparently rare in Tennessee though widely distributed throughout the United States. Most North American collections of the species are from epigean waters; however, the single Tennessee record is from Bigmouth Cave in Grundy County (Yeatman, personal communication).

Genus *Paracyclops* Claus

Paraclops fimbriatus poppei (Rehberg). Of the *Paracyclops* species known from North America, only *P. fimbriatus poppei* has been collected in Tennessee. The subspecies is worldwide in distribution and seems to prefer shallow weeded areas of lakes and ponds, but may also occur in flowing water (Rylov, 1948). Green (1933) first reported the subspecies from the state in collections from Andrew Jackson Lake during January and February. Yeatman (personal communication) records it from a spring in Franklin County, and I have collected it in a small pond in Blount County. It may also inhabit some of the larger reservoirs in the TVA system. Mr. Donald Wade and Mr. Don Dycus of the TV9 have identified it from vertical plankton hauls taken from Kentucky, Wilson, Barkley, Nickajak, Pickwick, and Sequoyah Reservoirs.

Genus *Tropocyclops* Kiefer

Tropocyclops prasinus (Fischer). A common and widespread limnetic species in North America (Yeatman, 1959), *T. prasinus* occurs in a wide variety of habitats (see Rylov, 1948 and Comita, 1951). Rylov (1948) indicated the planktonic nature of the species and noted that it was not generally reported from the macrophyte vegetation in lakes. Marsh (1910) reported a preference for lakes rather than pools, while Margalef (1953) found the species to be rarely planktonic. Most of my collections have indicated that it is usually found in small ponds and lakes where it appears to reach maximum abundance during the summer and fall months. It may also be a major form in the plankton of some reservoirs. I have identified it from Ft. Loudon, Fontana, Norris, Chilhowee, Watauga, and Melton Hill Reservoirs in Tennessee and North Carolina, and from Hartwell Reservoir in South Carolina.

Published records for the species in Tennessee include the Elk River and Woods Reservoir (Yeatman, 1956), Reelfoot Lake (Hoff, 1944) and Andrew Jackson Lake and surrounding sinks and ponds in Knox County (Green, 1934).

Summary

Of approximately 50 cyclopoid copepods known from North America, 22 are listed in this report from Tennessee; eight are reported for the first time. With additional collections from the western part of the state and from rarely sampled habitats such as wells, springs, small streams, temporary pools, and caves, the number should reach about 27. Species expected to occur in the state include *Mesocyclops tenuis*, found in Arizona and also reported from Kentucky (Geiling, 1962); *Macrocyclops ater*, uncommon, but probably widespread in North America (Yeatman, 1959); *Cyclops nearcticus*, reported from Texas, North Carolina, Massachusetts (Yeatman, 1959), and Missouri (from my own collections); *Cyclops jeanneli*, reported from North Carolina and Indiana (Yeatman, 1959); and *Cyclops navus*, found in Canada, the northern United States, and North Carolina (Yeatman, 1959), and in northern Alabama (from my own collections).

I am indebted to my students, past and present, for their efforts in helping to collect and process the samples, and to Don Wade, Don Dycus, and Jane Bickel of the Tennessee Valley Authority for providing information on reservoirs. Special thanks are due Dr. Harry C. Yeatman for providing his unpublished records.

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