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Seasonal Patterns and Abundance of Copepods in Kentucky Lake, USA

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ABSTRACT

The distributions and abundance of free-living copepods in Kentucky Lake were examined for the years 2000, 2002, and 2004. Vertical tow samples were collected from 16 sites every 16 days for April through November and every 32 days for December through March as part of a long-term physicochemical and biological monitoring program. Copepods comprised 14.39% of the zooplankton in tow net samples, but only 6 species were abundant. *Ectocyclops phaleratus, Cryptocyclops bicolor, Mesocyclops tenuis, Eurytemora affinis, Leptodiaptomus siciloides,* and *Acanthocyclops vernalis* accounted for 86.44% of adult copepods. With the exception of *E. affinis* that was found throughout the year, observed seasonal density maxima occurred at differing points during the year for each of the other major species. Most species were present during spring and summer and absent or found in low numbers throughout the remainder of the year. *A. vernalis, M. tenuis,* and *C. bicolor* exhibited density decreases that corresponded with day 160. Day 160 also marked rapid declines of other common zooplankton such as *Bosmina* sp., *Daphnia retrocurva,* and *Diaphanosoma* sp. Similarities in annual distribution patterns among all zooplankton suggest that common factors are exerting influence on abundances and seasonal distributions.

KEY WORDS: Zooplankton, Copepoda, Calanoida, Cyclopoida, Kentucky Lake, seasonal abundance

INTRODUCTION

Copepods are a common component of the zooplankton in most lakes and reservoirs (Wetzel 2001) but often receive less attention than the more abundant and more easily identified Cladocera (Williamson and Reid 2001). Construction of thousands of reservoirs throughout the world over the past 70 years has provided an array of new habitats for aquatic biota (Thornton et al. 1990; Pinto-coelho 1998); however, zooplankton communities have gone largely unstudied in most (Marzolf 1990). In 1988, the Center for Reservoir Research at Murray State University initiated the Kentucky Lake long-term monitoring program (White 1990). A focus of monitoring has been to document long-term trends and spatial variability in water quality, zooplankton, and phytoplankton.

Previous publications on Kentucky Lake have documented seasonal and aerial patterns of zooplankton, primarily Cladocera (Schram and Marzolf 1993), establishment and bioenergetics of *Daphnia lumholtzi* (Yurista et al. 2000, Yurista 2004) and rotifer populations (Albritton and White 2004, 2006). The focus of this study was to examine seasonal distributions of Kentucky Lake copepods based on zooplankton samples archived from the long-term monitoring for the 2000, 2002, and 2004 sampling years.

MATERIALS AND METHODS

Study Site

Kentucky Lake in western Kentucky and Tennessee is the lowermost of nearly 50 reservoirs on the Tennessee River system and was completed in 1944 by the Tennessee Valley Authority (TVA) for electric power, flood control, and navigation. Kentucky Lake is 296 km long and typical of mainstem reservoirs in being narrow (~3.2 km wide) with numerous small side-arm embayments. Water levels are comparatively constant with a summer pool at 109.4 m above msl from April to August and a winter pool of 107.9 m above msl from October through March. Yurista et al. (2004) have documented physical and water chemistry patterns.

Sampling Methods

Monitoring cruises have been conducted every 16 days during the months of March through November and every 32 days during the months of December through February at

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16 sites (Figure 1) since August 1988. Zooplankton have been collected by two methods. One vertical tow using a Wisconsin net (13 cm diameter mouth, 63 μm mesh) was taken at each site from one meter off the lake bottom. Three Schindler trap samples were taken at the depth of the 1% light level (63 μm mesh sieve). All samples were rinsed into 120 mL tissue culture flasks for holding. Samples were returned to the laboratory where they were anesthetized with 2 ml of soda water for 1 hr and then preserved in 10% formalin buffered with $CaCO_3$. Cladocerans were initially identified to species and copepods were identified to order, then samples for each site were composited for archiving.

Counts and Identification

Three years of archived samples were chosen for examination in this study, 2000, 2002, and 2004. Composites for each cruise date were sub-sampled using a sample splitter (Ocean Research Equipment, Inc.) until a sample size of approximately 100 zooplankton was reached. Identification and counts of copepods were done at 100–450×. When necessary, specimens were dissected at 42× and then mounted on glass slides using water miscible CMC-9 (Masters Company, Inc.). Mature calanoids and cyclopoids were identified to species. Harpacticoids were identified to genus except for *Phyllognathopus viguieri.* Keys used for identification of Calanoida, Cyclopoida, and Harpacticoida were Wilson and Yeatman (1959), Pennak (1989), and Williamson and Reid (2001). Copeodites and nauplii were not apportioned.

Analysis

Data from each of the three years were entered into Microsoft Access 2003 for comparison and analysis. Cruise data were obtained from the Kentucky Lake Long-Term Monitoring Program database to determine the total water volume sampled (vertical tows plus Schindler trap samples) on each sampling date along with average water temperatures collected with a YSI 6280 multiparameter probe. Separate years were combined by day-of-year on the same figure in Microsoft Access 2003 to provide visual representations of yearly and temperature related patterns.

RESULTS

In total, fourteen taxa plus copepodites and nauplii were identified, only six of which appeared in any abundance: *Ectocyclops phaleratus, Cryptocyclops bicolor, Mesocyclops tenuis, Eurytemora affinis, Leptodiaptomus siciloides,* and *Acanthocyclops vernalis* (Tables 1, 2). Cyclopoids dominated the total composition of the sub-samples and comprised 71.76% of all copepods identified, while calanoids accounted for 27.00%. Harpacticoids and nauplii comprised 0.71% of the samples only one of which (*Phyllognathopus viguieri*) was identified to species. The remaining 0.53% not reported was due to rounding restrictions. The harpacticoid taxa collected most likely were benthic and are not discussed further beyond the listing in Table 1. Other copepod taxa were present but either were too damaged to identify or could not be identified with certainty.

Total densities ranged from <0.01 l^{-1} in mid-December to 6.77 l^{-1} in mid-June. Peak densities occurred in late spring and early summer (Figure 2a). Cyclopoida densities were highest in early spring, while peak Calanoida densities occurred about 45 days later in early summer (Figure 2b). Cyclopoids dominated the copepod community from January through September, and calanoids dominated from September through December. Peak cyclopoid densities were more than twice those observed for calanoids.

Statistical analyses were run on the resulting distributional data and collected physiochemical data in an attempt to find causal relationships between the two. Our analysis did not reveal any single factor, or combination of factors, that directly affected annual distribution or density. It is quite possible that parameters other than those routinely monitored during our sampling cruises are instrumental in this role.

Late winter–early spring copepod populations were dominated by *Cryptocyclops bicolor,* which was most commonly found between days 80 and 160 and sharply declined before day 180 (Figure 3a). Observed distribution patterns for *C. bicolor* were most similar in 2000 and 2002 and exhibited a roughly bimodal distribution during these years. Distribution during 2004 differed in that it was un-

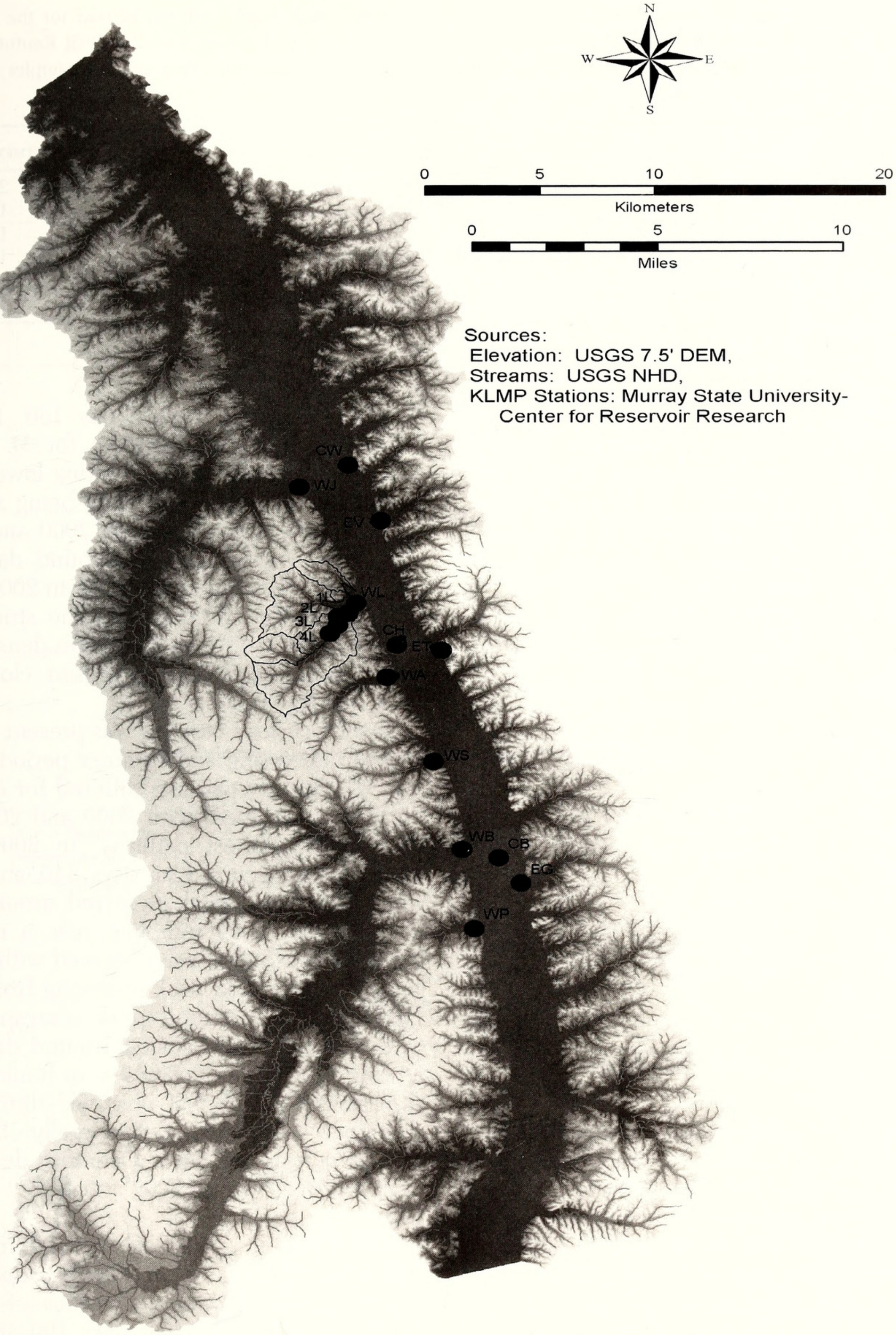


Figure 1. Map of Kentucky Lake showing locations of CRR monitoring stations. Letters refer to site names in the database.

Table 1. Species and average densities of copepods found in CRR Kentucky Lake Long-Term Monitoring Program sub-samples for the years 2000, 2002, and 2004. (0.53% missing due to rounding).

Family	Genus/species	Avg. annual density (liter^{-1})	% of all copepods
Calanoida			
Diaptomidae	*Leptodiaptomus siciloides* (Poppe)	1.09	5.7
Temoridae	*Eurytemora affinis* (Lilljeborg)	0.83	4.3
Copepodites		3.05	15.8
Other[1]		0.24	1.2
Total calanoids		5.21	27.0
Cyclopoida			
Cyclopidae	*Ectocyclops phaleratus* (Koch)	3.31	17.2
	Mesocyclops tenuis (Marsh)	2.43	12.6
	Cryptocyclops bicolor (Sars)	2.28	11.8
	Acanthocyclops vernalis (Fischer)	1.25	6.5
	Cyclops exilis Coker	0.76	4.0
	Mesocyclops edax (Forbes)	0.29	1.5
Copepodides		3.04	15.7
Other[1]		0.47	2.4
Total cyclopoids		13.84	71.8
Harpacticoida			
Tachidiidae	*Microarthridion* sp.	0.06	0.3
Macrobiotidae	*Macrobiotus* sp.	0.02	<0.1
Canthocamptidae	*Canthocampus* sp.	0.02	<0.1
	Moraria sp.	0.02	<0.1
	Maraenobiotus sp.	<0.01	<0.1
Phyllognathopodidae	*Phyllognathopus viguieri* (Maupas)	<0.01	<0.1
Total harpacticoids		0.12	<0.1
Nauplii		0.13	0.7

[1] Includes specimens that could not be identified positively.

Table 2. Peak density and day of year for the six most abundant copepod species found in CRR Kentucky Lake Long-Term Monitoring Program sub-samples for the years 2000, 2002, and 2004.

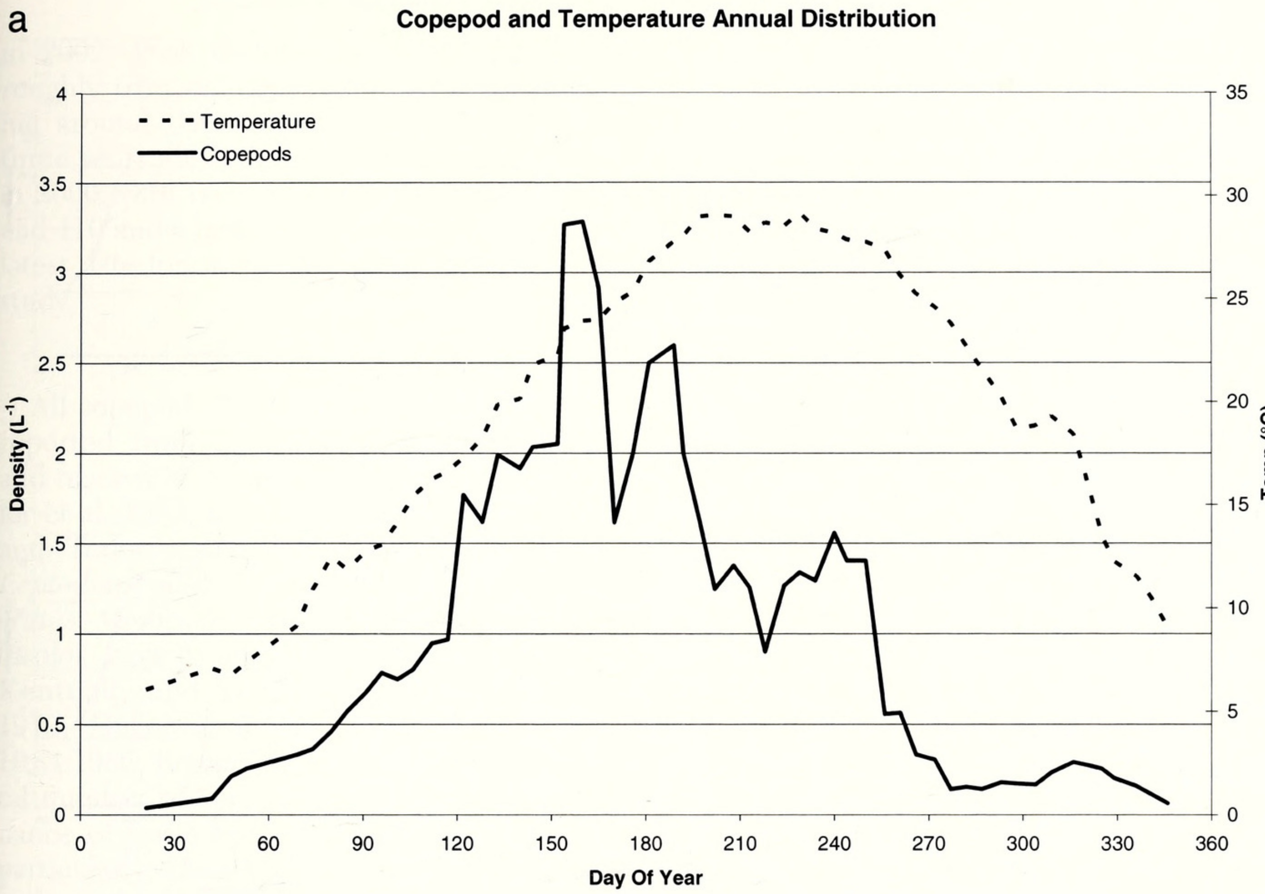
Species	Peak density (liter^{-1})	Day Of year
Ectocyclops phaleratus	1.25	240
Mesocyclops tenuis	2.34	155
Cryptocyclops bicolor	0.61	111
Acanthocyclops vernalis	0.42	122
Leptodiaptomus siciloides	1.00	189
Eurytemora affinis	0.36	170

imodal, and peak densities were reached around day 100, which corresponded with a trough between peak densities in 2000 and 2002. During all three years examined, there was a late summer increase in densities between days 220 and 260, but densities were low and population increases were not seen again until the following spring.

Following the presence of *C. bicolor, Mesocyclops tenuis* began to appear and was most commonly found between days 90 and 180 (Figure 3b). Observed patterns were different for all three years examined but were most common between 2000 and 2002 when peak densities occurred around day 150. During 2004, the distribution pattern for *M. tenuis* was markedly different, exhibiting lower densities than the other years and being skewed towards early spring. In both 2000 and 2002 there was a sharp decline around day 180. Densities observed for *M. tenuis* in 2002 were the highest for all species in the study and reached 2.34 l^{-1}, nearly twice the density observed in *E. phaleratus,* the next closest in peak density (Table 2).

Acanthocyclops vernalis was present during mid to late spring and summer periods (Figure 3c). Density patterns differed for each of the years examined, with 2000 and 2002 exhibiting the closest patterns. In 2000, two small peaks occurred at days 110 and 150, while the major peak occurred around day 200. For the 2002 sampling year, a roughly bimodal distribution was observed with a longer, more extended peak occurring from days 120–150 and a second peak corresponding with that observed in 2000, around day 200. During 2004 peak densities were found to be approximately half that observed during the other two years and were generally offset by approximately 20 days. Greatest densities were observed during 2002 at 0.42 L^{-1} on day 122.

The most common species through much of the spring and summer was *Ectocyclops phaleratus,* reaching average densities of nearly 0.70 individuals l^{-1} about days 190 and 240 (Figure 3d) with a maximum density of 1.25 l^{-1} (Table 2), in 2004. Peak densities were during the same period of time in 2000 and 2004, while peak densities in 2002 were found approximately 40 days earlier. Although the period during which the 2002 peaks occurred a



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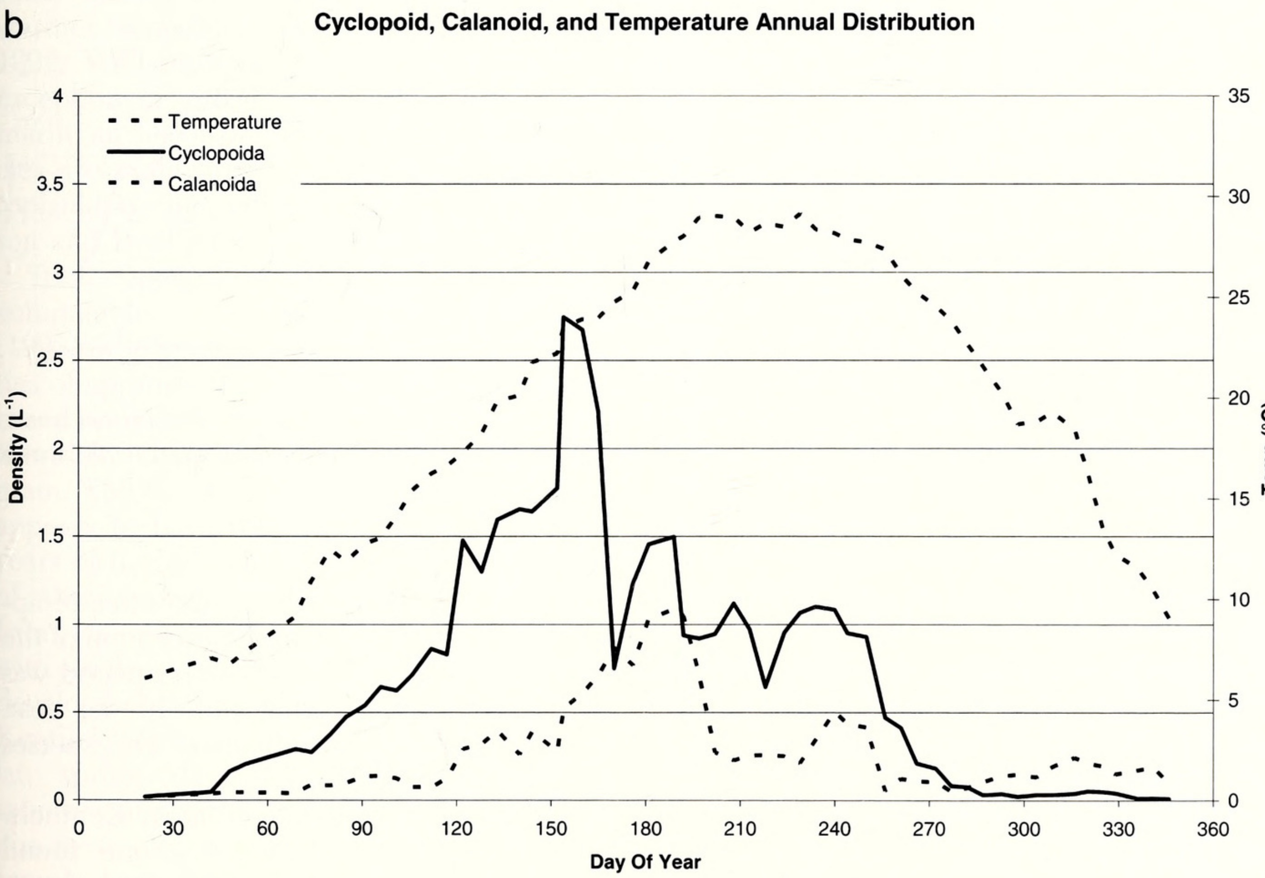

Figure 2. Average densities (3 point moving averages) and temperature distribution by day of year for (a) all copepods and (b) Calanoida and Cyclopoida.

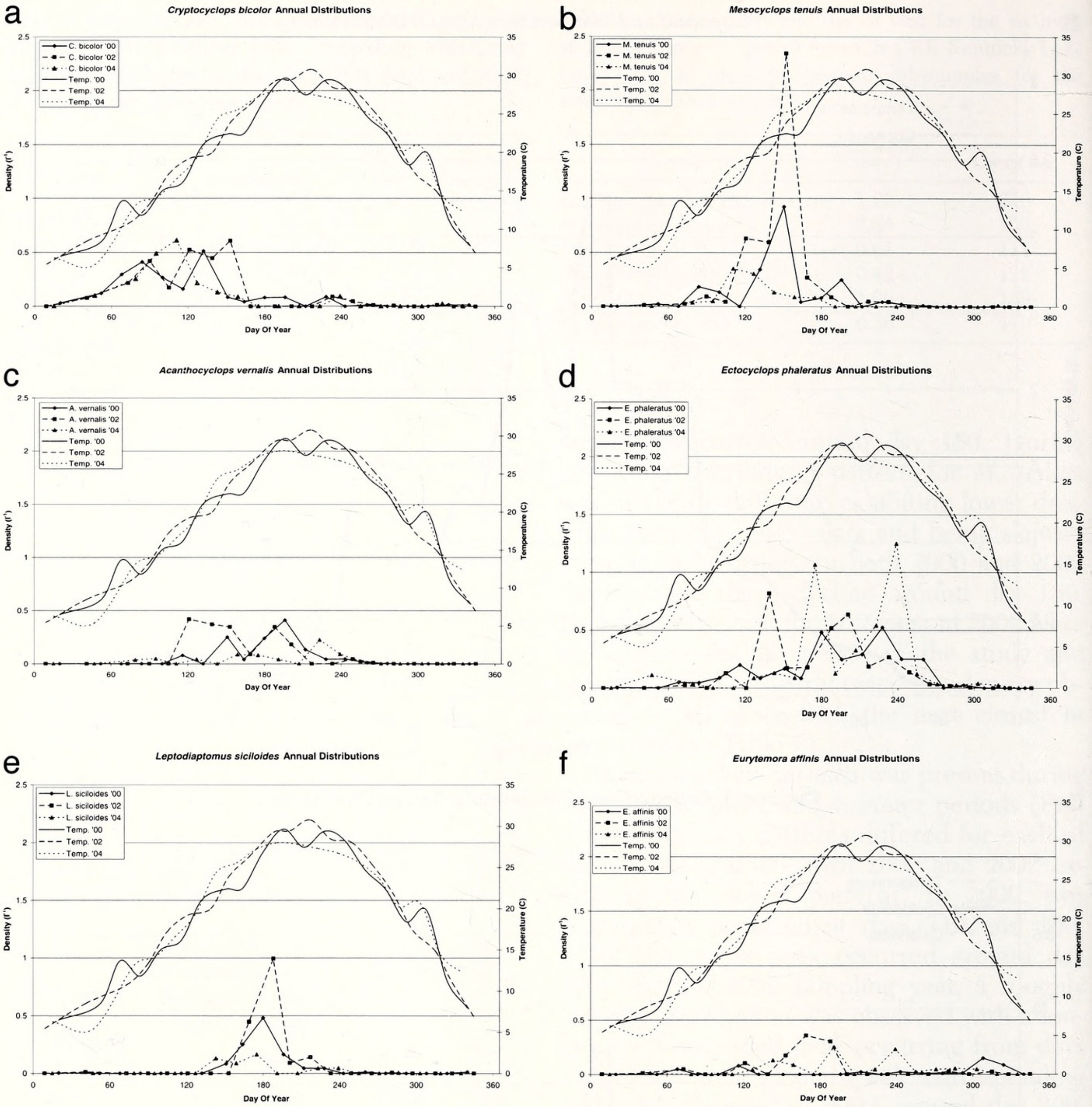

Figure 3. Density and temperature distribution by day of year for (a) *Cryptocyclops bicolor,* (b) *Mesocyclops tenuis,* (c) *Acanthocyclops vernalis,* (d) *Ectocyclops phaleratus,* (e) Calanoida *Leptodiaptomus siciloides,* and (f) Calanoida *Eurytemora affinis.*

was different, a bimodal pattern was still present.

Distinctly concentrated in the middle of the year was the calanoid *Leptodiaptomus siciloides* (Figure 3e). Although differences were seen between the 2000, 2002, and 2004 samples, the same general pattern was observed exhibiting peak densities around day 190. Of the three years sampled, highest densities occurred in 2002 and peaked at 1.00 l^{-1} (Table 2). *L. siciloides* was least common during the 2004 sampling year, reaching densities of approximately 0.20 l^{-1}. With the exception of the period from days 130–250, this copepod was rarely found at any other time of the year, making it the least common of the species identified in this study.

Of the major species present in Kentucky Lake, *E. affinis* was the only one found throughout the year (Figure 3f). Peak densities were at different times in all three years, with the highest density of 0.36 l^{-1} on day 170 in 2002. Peak densities in 2004 exhibited a roughly trimodal distribution with peaks falling around days 140, 200, and 240. Of the three years, densities of *E. affinis* were lowest in 2000, with two small peaks around days 70 and 110 and a larger peak around day 310, the latest date for any of the major species in this study.

DISCUSSION

All copepods found in this study have been reported from other North American lakes and reservoirs (Bowman and Lewis 1989; Taylor et al. 1993; Lee 1999; Reid 1999; Nicholls and Tudorancea 2001). *Eurytemora affinis, Leptodiaptomus siciloides, Ectocyclops phaleratus, Mesocyclops tenuis,* and *Cryptocyclops bicolor* have been reported previously from Kentucky and Tennessee waters (Bunting 1973; Heller and Katz 1982; Novotny and Hoyt 1982; Bowman and Lewis 1989). The total number of species present and the dominance of just a few calanoids and cyclopoids, particularly *Mesocyclops tenuis,* in the Kentucky Lake plankton appear typical for most warmer temperate lakes and reservoirs (Reid 1992; Williamson and Reid 2001). With the exception of *Eurytemora affinis* that is primarily an herbivore, the majority of the species are omnivores feeding on bacteria, phytoplankton, and other zooplankton (Williamson and Reid 2001).

Total copepod densities in this study were comparable to those of Schram and Marzolf (1993) who reported average summer densities of approximately 3.0 l^{-1} in Kentucky Lake based on data from the first three years of the Kentucky Lake Long-Term Monitoring program. The timing of the spring copepod peak appears to have remained constant over the years of the monitoring program independent of water temperatures, lasting about 32 days from late April through May and coinciding with similar peaks in cladocerans and the early development of zooplanktivorous larval fish in Kentucky Lake (Schram and Marzolf 1993). A late spring (days 150–160) change in community composition was observed and is likely due to an increase in larval fish predation and temperature change.

As with cladocerans (Thrope and Covich 2001; Wetzel 2001), several of the copepod taxa reached maximum densities before day 160 and were replaced by other dominants after. For Kentucky Lake, the cyclopoids *Cryptocyclops bicolor* and *Mesocyclops tenuis* were the late spring species (Figures 3a, 3c), while the calanoids *Eurytemora affinis* and *Leptodiaptomus siciloides* peaked in early to midsummer (Figures 3d, 3e). Only the cyclopoids *Ectocyclops phaleratus* and *Acanthocyclops vernalis* were present in similar numbers before and after the day 160 (Figures 3a, 3f). *Eurytemora affinis* (Figure 3d) did not show a density response related to day 160.

At least some cyclopoids and calanoids were present throughout the year, but populations did not greatly increase until water temperatures reached approximately 10°C (Figure 2b), which concurs with summaries in Williamson and Reid (2001). Populations of most species, with the exception of *Ectocyclops phaleratus,* declined before the late summer maximum of 30°C. Similar temperature relationships also have been shown for most Kentucky Lake cladocerans (Schram and Marzolf 1993; Yurista et al. 2000).

Although life histories could not be obtained for all of the major species in this study, they were found for *E. phaleratus, L. siciloides,* and *E. affinis* (Hudson et al. 2003; Lesko et al. 2003). Annual patterns observed for *E. phaleratus* in Kentucky Lake density peaks approximately every 30 days through spring and summer while the reported life cycle of *E. phaleratus* from Minnesota is 12 days. This may be a result of differing environmental factors, the limits of our dataset and sampling frequency, or multiple generations being present concurrently. Annual patterns for *L. siciloides* were observed to rise and decline sharply, peaking around day 180 while their life cycle is reported to last from 26–73 days. These data more closely resemble the reported life history of the species and the single rise in density observed in this species may be the result of these females only being able to produce one clutch of eggs each generation. Finally, *E. affinis* exhibited density peaks approximately every 30 days with the exception of a 60 day peak observed in 2002. Life history accounts report that this species will have a <30 day life cycle at 25°C and corresponds with the density increases observed in our study. The extended peak observed in 2002 may be the result of multiple overlapping generations.

Eurytemora affinis is considered a marine invasive in freshwater systems and generally restricted to temperatures of <17°C (Taylor et al. 1993). Although it was present in Kentucky Lake in low numbers throughout the year, the maximum density was not reached until temperatures reached 17°C and higher. Locally it has been collected from the Ohio River at Louisville, KY (Bowman and Lewis 1989). *Eurytemora affinis* is an herbivore and may take advantage of increasing algal resources at this time of year. Although we have not examined earlier archived samples to determine if this species had been present throughout the entire monitoring period, it is of interest to note that other warm water zooplankton species (e.g., *Daphnia lumholtzi,* Yurista et al. 2000) have invaded Kentucky Lake over the period of monitoring creating a continually changing mosaic of species and species interactions in this human created ecosystem. Continued monitoring of Kentucky Lake zooplankton through the CRR's long-term monitoring program may lead to further insights and a better understanding of copepod ecology and population dynamics.

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